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ABSTRACT

Discussions of research efforts in areas supported by the National Science Foundation (NSF) are presented. These areas include: (1) mathematical and physical sciences (mathematical sciences, computer science, physics, chemistry, and materials research); (2) engineering (electrical, computer, and systems engineering, chemical and process engineering, civil and environmental engineering, mechanical engineering and applied mechanics, and interdisciplinary research); (3) biological, behavioral, and social sciences (physiology, cellular, and molecular biology, environmental biology, behavioral and neural sciences, social and economic sciences, and information science and technology); (4) astronomical, atmospheric, earth, and ocean sciences, including United States arctic and antarctic research activities; (5) scientific, technological, and international affairs (industrial science and technological innovation, intergovernmental and public-service science and technology, international scientific cooperative activities, policy research and analysis, and Science Resources Studies); (6) scientific and engineering personnel and education; (7) coordinated agency-wide research activities; and (8) ocean drilling. Also included in appendices is a summary of the NSF financial report for fiscal year 1982, a list of NSF advisory committees and panels, a list of patents and inventions resulting from NSF-supported activities, and a list of National Research Center contractors. (JN)

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National Science Foundation Annual Report 1982

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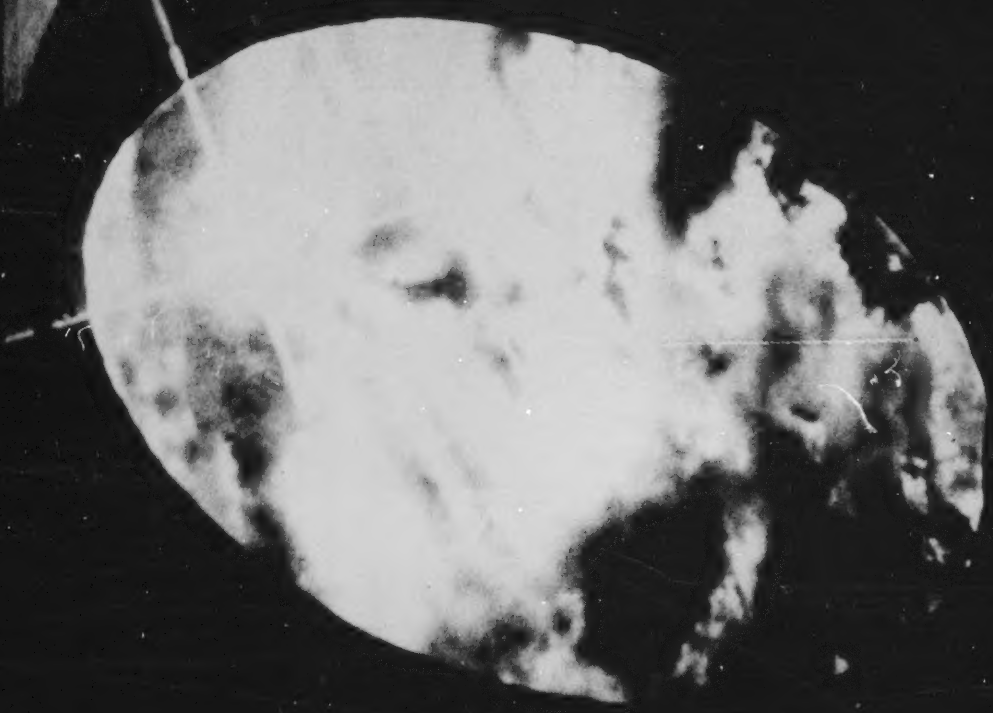

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Cover: Sunlight shines on mirror of McMath Telescope at Kitt Peak National Observatory (see astronomy section of this report).

National Science Foundation

Thirty-Second Annual Report for Fiscal Year 1982

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Letter of Transmittal

Washington, D.C.

DEAR MR. PRESIDENT:

I have the honor to transmit herewith the Annual Report for Fiscal Year 1982 of the National Science Foundation, for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,

Edward A. Knapp

Edward A. Knapp
Director, National Science Foundation

The Honorable
The President of the United States

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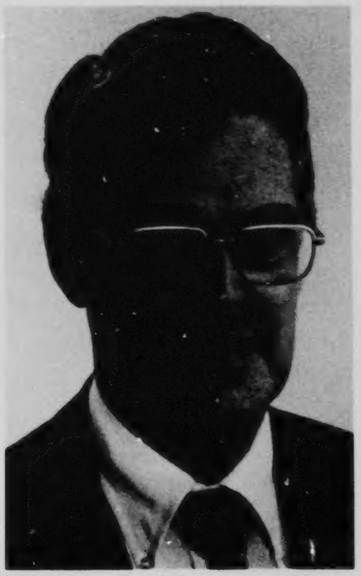
Achievements and Challenges



EDWARD A. KNAPP
Director

Nineteen eighty-two was a year of discovery and excitement in science and technology, as you will see in the report that follows. In this preface I want to do two things: mention some NSF-supported accomplishments of the past year and suggest future directions for the Foundation.

If we look at the spectrum of research being supported by NSF, we find scientists seeking answers to basic questions about life and matter from beneath the floor of the ocean to billions of light years away. They are also at the "top" and "bottom" of the earth, in the Arctic and Antarctic. This work is being done by individuals, by interdisciplinary teams, and by university-industry consortia.

You will read about 1982 achievements in detail in this volume, but let me highlight a few here:

- *Astronomy*—Today there is great popular interest in this oldest of the sciences. Small wonder, since few other disciplines can question so directly the past, present, and future of the universe. NSF-supported astronomers have now observed a radio source that may be a black hole at the center of the Milky Way. They have also confirmed the theory that white dwarf stars pulsate and discovered possible connections between sunspots and weather on earth.
- *Atmospheric Sciences*—Airport weather studies near Denver in the summer of 1982 have helped us understand why some major air crashes may have occurred. Weather forecasters, airlines, aircraft manufacturers, and others are already applying the results of this basic research project.
- *Physics*—In 1982 an MIT team showed experimentally that the electromagnetic vacuum can be altered, thus opening a whole new area of research in the spontaneous decay of particles. In the world of grand unified theories, an exciting development is the possible observation of a magnetic monopole in 1982 by an NSF-backed investigator at Stanford University.
- *Chemistry*—Industry and university researchers working together developed a new type of chemical reactor. This membrane reactor is expected to perform catalytic processes that need less energy and a smaller capital investment than devices now in use. Other chemists have been incorporating homogenous catalysts into clays, which may become even more useful than they already are in the manufacture of certain products.
- *Physiology/Cellular and Molecular Biology*—Here investigators made the discovery that DNA, the basic genetic material, exists in a second form—a counterclockwise double helix called Z-DNA. In other genetic research, scientists succeeded in not only introducing a foreign gene into mouse embryos but also triggering the expression of that gene in the resulting adults.

- *Computer Science/Computer Engineering*—There has been progress in efforts to duplicate in computers human functions related to vision, speech, and understanding language. Already developed are robots that can sense their environment through machine vision systems and touch sensors.
- *Ocean Sciences/Ocean Drilling*—Oceanographers made the surprising find off the coast of western Mexico that fast-growing, gas-producing bacteria exist in superheated water coming from deep-sea hydrothermal vents. In the eastern equatorial Pacific, ocean drill teams doing geophysical experiments went almost twiceas deep as ever before into oceanic crust—1,350 meters below the sea floor.

The Challenges

Certainly these are exciting accomplishments. But we are also aware of some tough problems we face. In the past, American science and technology have been the envy of the world, but they are in trouble now.

First, we no longer have enough excited, enthusiastic graduate students and postdoctoral fellows preparing for careers in mathematics, science, and engineering in this country's universities and colleges.

Second, we as a nation are seriously underinvesting in state-of-the-art instrumentation and facilities in academic institutions.

Third, our system of public education has not prepared enough high school students for scientific training or, more sadly, for living in a technological age.

In a time of economic transition—and with a limited budget for federal support—how do we stimulate innovation, increase productivity, and regain overall technological superiority?

At NSF we are planning a strong, well-balanced program for the future. We will continue to support a great deal of very exciting basic research, with particular emphasis on areas of greatest potential promise to our future economic well-being and technological capabilities. Other important criteria are the scientific excellence of an activity, the need to sustain momentum in certain key areas, and maintenance of a broad base of support across a wide variety of scientific disciplines.

Our program for the future will also work to ensure quality education in science and mathematics in our nation's secondary schools. And it will strengthen research training for graduate science and engineering students in our colleges and universities. These are the institutions in which most long-term, fundamental research is done and in which our future scientists and engineers are trained. The NSF dual goal of research and education inextricably links these two functions and has led to the evolution of our university-based system of basic research, a system that has served us remarkably well. Thus, in some sense, almost the entire Foundation budget goes for science and engineering education.

The revitalization of our universities as exciting places to conduct research and train new generations of scientists and engineers is an important challenge for this nation. As part of that revitalization, we will put a big emphasis on helping universities with their equipment needs. After all, research instrumentation provides the essential means through which the scientist asks questions and gets answers from nature. It is of central importance to the conduct of cutting-edge research in virtually every field of science and engineering today. I am proud of the leadership role the Foundation has played—and will continue to play—in urging other federal agencies, the private sector, and universities to focus on this major concern.

Finally, NSF expects to see, and hopes to promote, closer cooperation between universities and industry in the future. Just as research results in one scientific discipline often illuminate a problem in another discipline, industry and universities working together can shed light on each other's problems.

We have some ambitious tasks on our agenda. But we remind ourselves that science and technology have long been at the heart of our economic competitiveness and national security. Whether it be the computer in the business world or high technology for national security, energy, or health, scientific discovery and scientifically trained leaders have fundamentally changed and improved our lives. Our nation must move forward into the 1980s with a vigorous program of research and training. This will assure our economic well-being and competitiveness in the world, as well as a stable and secure defense posture.

I believe that the most valid, overriding goal for the Foundation to pursue now and for the foreseeable future continues to be maintaining the health and vitality of this nation's science and engineering enterprise. We intend to keep working very hard on that agenda.

Mathematical and Physical Sciences

1

Research in the mathematical and physical sciences has the goal of developing a fundamental understanding of the physical laws that govern the world and the universe in which we live. To further this objective, NSF supports activities in the disciplines of mathematics, computer science, physics, chemistry, and materials science. Research results in these fields provide the underlying knowledge for the future technological developments upon which our economic and social well-being depend. They also contribute much to the intellectual underpinning of the biological, environmental, and behavioral sciences and of engineering. And they provide many of the research instruments and techniques needed for progress in these fields.

More specifically, research in the mathematical and physical sciences strengthens the nation's research capability by:

- Creating new mathematical knowledge and applying that knowledge to achieve a better understanding of physical and social phenomena.
- Developing an understanding of the science that underlies computational processes and formulating the basic principles that govern the design of computing and information-handling systems.
- Advancing knowledge of the fundamental physical laws governing matter and energy, with the ultimate goal of achieving a unified, self-consistent explanation of all physical phenomena.
- Stimulating the development of modern chemistry on a broad front, including chemical synthesis, analysis, dynamics, structure, and theory.
- Developing a better understanding of the fundamental principles, phenomena, and concepts that govern the physical, chemical, and mechanical properties of materials.

This chapter describes some of the accomplishments of NSF-supported investigators in the mathematical and physical sciences. A common element in the research described is the critical dependency of researchers on the availability of sophisticated, modern, state-of-the-art instrumentation and facilities. From the descriptions, it is evident that:

1. In the mathematical sciences, there is a growing emphasis on the use of computers for mathematical research.

2. Recent advances in computer science can be attributed to the design of "expert systems," which simulate the human thought process.

3. High-energy physics results, such as the detection of quarkonium, would not have been possible were there no such facility as the Cornell Electron Storage Ring (CESR). Nor would the possible observation of magnetic monopoles—a prediction of the grand unification theories—have occurred had ultrasensitive detection devices not been developed.

4. In chemistry, the development of lasers that produce intense radiation has changed the "symmetry rules" that were believed to govern the sequence of events in a chemical reaction. This radiation, which acts as a catalyst, has opened up new reaction pathways.

5. Advances in sophisticated, high-resolution electron microscopy make it possible for materials scientists to image the configuration of atoms and clusters of atoms and to determine their chemical composition. In addition, the advent of pulsed sources of high-intensity synchrotron radiation makes it practicable for these scientists to study structural rearrangements under varying conditions on a time scale not attainable before.

Table 1
Mathematical and Physical Sciences
Fiscal Year 1981 and 1982

(Dollars in Millions)

	Fiscal Year 1981		Fiscal Year 1982	
	Number of Awards	Amount	Number of Awards	Amount
Mathematical Sciences	972	$ 28.27	910	$ 30.49
Computer Research	266	22.33	289	25.74
Physics	427	72.09	458	75.32
Chemistry	875	57.62	872	61.36
Materials Research	766	76.17	740	79.93
Total	**3,306**	**$256.48**	**3,269**	**$272.84**

SOURCE: Fiscal Years 1983 and 1984 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Mathematical Sciences

Research in mathematics involves the discovery and study of the formal, abstract structures that underlie our world. Emphasis is on structures of broad intellectual applicability and those reflecting fundamental aspects of the real world. Mathematics is a natural language to describe the activities and laws of nature and is thus an indispensable undergirding of science.

Mathematics has played a key role in the development of physical sciences and technology; they in turn have been the wellspring of much mathematics. Thus there has developed a discipline of mathematics qua mathematics (sometimes called pure or core mathematics) and one of applied mathematics, which involves the modeling and analysis of complex, real-world phenomena. (Statistics, as well as the probability theory that underlies it, is obviously a kind of applied mathematics. However, this is such a distinct field that it is almost always described separately. Statistics involves collecting and processing data and devising methods to draw inferences from limited data.)

Mathematical analysis began with the invention of calculus in the 17th century; it continues to attract more mathematicians, both pure and applied, than any other single field. Some continue to work on classical problems with techniques that would not have surprised an 18th-century mathematician; others bring to bear tools from modern algebra and topology. Geometry runs the gamut from differential geometry, which has applications in relativity theory and general field theory, to the study of planes having only finite numbers of points (which has, among other applications, relevance to the design of magnetic core memories for computers). The field of foundations involves mathematical logic—with obvious relevance to computing machines—and the axiomatic theory of sets, the apparent paradoxes of which have stimulated some of the finest mathematics of the 20th century.

Algebra and topology are inextricably mixed; tools from each have been applied to the other, and the quest for more tools has then inspired substantial advances in both fields. Modern algebra focuses on the study of mathematical structures such as groups, modules, and rings. These structures—and the techniques used to study them—give insight into other areas of mathematics, such as algebraic geometry and number theory. Topology is, so to speak, a refined kind of geometry concerned with geometric properties that do not depend on distance or angle.

NSF's role in support of basic research in the mathematical sciences is pivotal. The Foundation provides virtually all of the federal funding for basic research in algebra, number theory, geometric and modern analysis, and foundations. In classical analysis NSF accounts for some 90 percent of the funding, with the Departments of Defense and Energy supplying the balance. In applied mathematics, probability, and statistics, the Foundation gives approximately 40 percent of the total funds for basic academic research. In these areas the programs of NSF, Defense, and Energy are complementary.

Research in the mathematical sciences continues to thrive under an expanding spectrum of stimuli from other disciplines. Within the field, one of the great themes of mathematics today is the growing synthesis of its parts. Associations between diverse areas such as topology and analysis, finite fields and computational complexity, and probability and linear programming are offering unexpected synergies. Research concentrating on nonlinear problems has led to progressively sharper models for users of mathematics in other sciences.

A second, more recent, theme—perhaps destined to become a major development—is the growing use of computers for scientific computation. This is true both for applied mathematics and for interactive computing in statistics and in pure or core mathematics.

The following sections describe some of the areas in which major activity is under way along each of these mathematical tracks.

The Four-Dimensional Poincaré Conjecture

Henri Poincaré conjectured at the turn of the century that topological spheres were the only topological manifolds that satisfied a short checklist of properties known to be enjoyed by such spheres. This seemed innocent enough at the time. In fact, Poincaré originally made the conjecture for the three-dimensional sphere (the surface of a solid four-dimensional ball), but it was shortly generalized to those of any higher number of dimensions by appropriately increasing the checklist of properties. (The conjecture is true and not difficult for the two-dimensional sphere—i.e., the surface of an ordinary, solid, three-dimensional ball.)

Over the next half-century the Poincaré conjecture resisted all efforts at proof. Several false proofs were announced and punctured, and a great body of algebraic and other techniques for doing topology evolved. Finally, in about 1960, Stephen Smale (now at the University of California, Berkeley) discovered that a proof for the five-sphere and all higher dimensional spheres could be obtained by using some of these techniques in a way that clearly did not apply to the three- or four-sphere. During the past year, Michael H. Freedman of the University of California, San Diego settled the four-dimensional Poincaré conjecture. Ironically, Freedman's result now leaves open only the original three-dimensional Poincaré conjecture.

Freedman's proof is novel, and his techniques have already led him and others to proofs of important related results. The techniques he uses draw upon two distinct traditions in topology. One, decomposition spaces, comes from the Texas school, descended from R. L. Moore via R. H. Bing and others. The second, algebraic techniques, is more characteristic of the Princeton school of topologists. Freedman, a student of William Browder of Princeton, received his Ph.D. in 1973.

The Unreasonable Efficiency of the Simplex Method

Among the many mathematical contributions to this nation during World War II was the development of linear programming and its application to a vast number of complex problems. However, it was not until 1949 that George Dantzig, in a landmark paper, introduced the so-called simplex method for solving such problems.

Briefly, linear programming involves management. This management, or decision making, may pertain to petroleum-product distribution, automobile production, economic decisions, diets, traffic control, or any of a host of problems involving a large number of variables. It is further complicated by constraints: Factories can produce only so many units each day, whatever their products; runways can handle only so many planes each hour, regardless of their size.

In linear-programming situations, it can always be shown that the maximum level of effectiveness (quality, profit, equipment use) exists. Where, in principle, one should look for the best choices is also known. Dantzig's simplex method does better than that; it provides a computational roadmap. Following a sequence of relatively easy steps, those using it can calculate accurately how their resources should be managed and what their expected maximum effectiveness will be.

The simplex method is ideally suited for use on computers, and many very large scale problems are run daily on high-speed computers throughout the country. Perhaps its most remarkable feature is its efficiency. Computer scientists measure efficiency by the time it takes to process a given problem in terms of the number of variables involved. For example, if a method processes a problem with 3 variables in 3^2 minutes and a problem with 10 variables in 10^2 minutes and a problem with 50 variables in 50^2 minutes, the method is said to compute in *polynomial time*.

If, on the other hand, a method requires 3^3 minutes for a problem with 3 variables and 10^{10} minutes for one with 10 variables and 50^{50} minutes for one with 50 variables, the method computes in *exponential time*. Examples have been given to show that the simplex method may require exponential time, which obviously can be very slow. But in practice this phenomenon never occurs. The simplex method is, in fact, very fast.

In a fairly recent manuscript, Stephen Smale of the University of California, Berkeley, using the reasoning of probability theory, explained the method's effectiveness. He showed that the chances of coming across a linear-programming problem for which the simplex method would require more than polynomial time are essentially nil.

Experienced users of the simplex method have felt that the time needed for computation grows in proportion to the number of variables. This is referred to as linear growth. Smale's result shows that on the average the simplex method is even better than that. In fact, it grows more slowly than any fractional power of the number of variables—that is, more slowly than the square root, cube root, fourth root, etc.

Computer Science

Many of the most fundamental concepts in computer science have come from mathematics. As pointed out in the writings of Jacob Schwartz of New York University, this heritage of ideas has accelerated greatly the development of computing as a practical activity. Examples are easy to cite:

- The computer industry could not have developed so rapidly without the principles of Boolean algebra created in the 19th century.
- Both the universal possibilities and the limits of programming were laid out at its very beginning, in the work of Alan Turing and Kurt Gödel.
- Renaissance algebra and 19th-century work on matrix algebra contributed essential concepts and notations toward developing the computer languages FORTRAN and APL.
- Notions and techniques drawn from matrix theory have been absorbed wholesale by computer science and have been fundamental to the design of many high-efficiency algorithms.

In turn, the young field of computer science has begun to exert a profound influence on some of the most significant branches of mathematics. This is bound to increase as computer science matures. A first and most obvious area is in numerical analysis; it has been revolutionized by the advent of the computer as dozens of new methods of numerical calculation have been developed.

Surprisingly, some of the new methods relate to areas worked on long ago by Isaac Newton, Karl Friedrich Gauss, and Adrien Legendre; modern mathematicians use methods that were easily accessible to these great classical figures. Further, combinatorics has been affected just as much: The computer influence here has been strengthened by the fact that many of the central algorithm design-and-analysis problems of computer science are combinatorial in nature. Thirdly, the possibility of doing extensive symbolic computations by computer has revived the study of constructive methods in algebra. It has also deepened understanding of techniques for carrying out even such classical processes as polynomial factorization.

Research in computer science has never been more exciting than it is today. Advances in very large scale integration (VLSI) circuit technology have presented new challenges and opportunities, which unite theoretical, software, and hardware research. These advances make it possible for universities, for the first time since the early 1950s, to become active participants in research on computer hardware and computer-systems architecture.

Major areas of academic research include algorithmic complexity, program semantics, programming languages, VLSI design and design support, distributed and concurrent systems, computer networking, software engineering, graphics, and artificial intelligence. The result is a rich intellectual environment that has unleashed much creative energy among academic researchers. The topics that follow can be only representative; however, they do convey the sense of excitement that permeates computer science research. And they illustrate a few of the ways in which basic research in computer science is solving both theoretical and practical problems.

Capturing Human Expertise in Computer Systems

Computer scientists have been devoting considerable time and effort to problems in this area. The term "knowledge engineering" has been used to describe this process; the computer programs equipped with human expertise have been called "expert systems." Typically, an expert system will follow problem-solving procedures used by human experts to help nonexperts solve complex problems.

To be useful, an expert system must have a knowledge base and an inference procedure. The knowledge base consists of facts and heuristics (rules of plausible reasoning and rules of good guessing) associated with a problem; the inference procedure is a complex control structure for using the knowledge base to solve the problem. The goal is to achieve a performance level comparable to or surpassing that of a human expert.

To date, computer systems have been developed to ease problem solving in a variety of knowledge-based areas. At Stanford University, for example, a team of researchers led by Edward Feigenbaum has come up with expert systems to aid in medical diagnosis, formulate rules of mass spectrometry, and analyze data in protein crystallography.

Recent work by Richard Stallman and Gerald Sussman at Massachusetts Institute of Technology has produced computer systems that can assist in the high-level design and analysis of electronic circuits. At Stanford Research International, Earl Sacerdoti has been working to develop computer systems for controlling robots that will be equipped with "human expertise" when planning and executing complex tasks.

There is also progress in duplicating human functions in the areas of vision, speech, and language understanding. Edward Riseman at the University of Massachusetts, Azriel Rosenfeld at the University of Maryland, and King-sun Fu at Purdue have led research projects on programming into a computer sensitivities to depth, space, texture, and motion.

At Carnegie-Mellon University, a group of scientists led by Raj Reddy has made significant progress in building knowledge-based systems to understand human speech. And at the University of Pennsylvania Aravind Joshi and his research team have been investigating ways for the computer to understand and engage in natural language discourse. In a sense, the key idea in each of these expert systems is to put knowledge to work for specific human endeavors.

As the field advances, new problems and issues continue to challenge the research community. For instance, most scientists now agree that the power and performance of an expert system come from its knowledge base, not its inference procedure. The critical issues concerning knowledge are "How does one acquire it from human experts or nature?" and "How can we represent it in the computer?"

Current efforts to solve these problems have been along the lines of developing:

- Smart editors that help enter and modify data on knowledge.
- An intelligent interface between the human expert and the computer, to ease the transfer of knowledge.
- A learning system that can induce facts and heuristics from examples or other sources.

Harnessing and extending these research efforts will have a major impact on future innovation in capturing human expertise in computer systems.

Combinatorial Optimization

Combinatorics deals with the arrangement, grouping, ordering, and selection of finite sets of objects. Traditionally, combinatorialists were concerned with problems of existence and enumeration—to wit: Is there a feasible arrangement (that is, one satisfying certain properties)? If so, how many feasible arrangements are there?

In problems of feasibility and optimization today, the existence of a feasible solution is generally not in question and the number of feasible solutions is irrelevant. What is important is testing feasibility efficiently, or finding an optimal solution, whether it be one in a hundred or one in an effectively infinite number of possibilities. Hence these are essentially computational questions.

Typical examples of combinatorial optimization problems are those that arise in the sequencing and scheduling of machines and work crews. Here one is concerned with the allocation over time of "machines" to activities known as "jobs." The object is to get a schedule that is "optimal" in some sense—for example, to get all the jobs done as soon as possible.

Under a Foundation grant, E. L. Lawler of the University of California, Berkeley undertook an investigation of machine-scheduling problems. One objective was to develop better computational techniques for solving these problems. Another aim was to apply the modern theory of computational complexity to this broad class of problems in an effort to classify them according to their inherent computational difficulty.

Working with two Dutch collaborators, J. K. Lenstra and A.H.G. Rinnoy Kan, Lawler developed a system of classification for machine-scheduling problems; it encompassed some 5,000 specific problem types. Using the computer in a novel way as an aid, they classified the individual problems

SIMPLE SINGLE MACHINE SCHEDULING PROBLEMS

JOB 1: DEADLINE 6 HOURS AFTER START OF MACHINE
TIME TO COMPLETE JOB—4 HOURS

JOB 2: DEADLINE 5 HOURS AFTER START OF MACHINE
TIME TO COMPLETE JOB—2 HOURS

JOB 3: DEADLINE 7 HOURS AFTER START OF MACHINE
TIME TO COMPLETE JOB—3 HOURS

PROBLEM 1: MINIMIZE THE TOTAL NUMBER OF JOBS THAT ARE LATE.

SOLUTION: ANY SCHEDULE EXCEPT FOR JOB 3, JOB 1, JOB 2, AND JOB 1, JOB 2, JOB 3 HAS EXACTLY ONE LATE JOB. THESE TWO SCHEDULES HAVE TWO LATE JOBS.

PROBLEM 2: MINIMIZE THE TOTAL HOURS OF THE LATE JOBS.

SOLUTION: JOB 2, JOB 1, JOB 3 IS THE UNIQUE SCHEDULE WHICH MINIMIZES THE TOTAL HOURS LATE—IN THIS CASE, 2 HOURS.

BEST COPY AVAILABLE

according to complexity, with about 80 percent found computationally difficult and about 10 percent computationally easy. The status of the remaining problems was open.

In the course of resolving as many of the open problems as possible, the team developed a number of new computational procedures. One of the most interesting was a way to solve a problem involving the "preemptive" scheduling of parallel machines with different speeds. This procedure is the work of C. U. Martel, now at the University of California, Davis and a coinvestigator with Lawler on his NSF grant; it turned out to have very wide applicability. The procedure suggested a generalization of the classical network flow model, one of the basic tools of combinatorial optimization. This new model should be an elegant and useful tool to unify much of the theory of combinatorial optimization.

Physics

In its search for fundamental laws governing matter and energy, the science of physics operates over a scale that encompasses the most elementary and minuscule constituents of matter and the largest aggregation imaginable—the universe. Physicists seek to incorporate all these phenomena into a unified theory, one based on detailed knowledge of the fundamental forces that act on components of the micro- and macroworlds.

The Foundation supports research in elementary-particle physics; intermediate and low-energy nuclear physics; atomic, molecular, and plasma physics; gravitational physics; and theoretical physics. The first of these studies the most elementary forms of matter; it includes searches for elementary particles and measurements of their properties and interactions. These particles fall into three families: leptons, quarks, and the gauge particles (carriers of the forces of nature, including photons, hypothetical intermediate-vector bosons, and gluons).

In the last few years, evidence for a fourth (charm) and fifth (beauty) quark has come forth. A new lepton (the tau) was also discovered, and indirect evidence for the existence of gluons was observed. There are candidates for bound states of two gluons (glueballs), along with some experimental indication that a magnetic monopole and free quarks may also have been observed.

Nuclear science, which includes intermediate and low-energy nuclear physics, is the study of nuclear structure and dynamics and the effects of the substructure of neutrons and protons on the characteristics of atomic nuclei. One area of current experimental interest centers on the interaction of nucleons at intermediate distances. At longer distances the older meson-exchange theories are still considered valid for describing nucleon interaction, and the more recent quark-gluon theory is gaining acceptance at very short distances. However, since neither approach can describe the interactions at intermediate distances, scientists are striving to design experiments that are sensitive to this transition region.

Atomic, molecular, and plasma physics includes the study of ground states of electrons, protons, and neutrons; the properties of their combinations into simple atoms and molecules (neutral and ionized); and the interaction of those atoms and molecules with one another and with electromagnetic and other fields. Included for study are the properties of plasmas.

Dramatic advances in photon sources have occurred in laser technology and synchrotron radiation. Moreover, ion sources, ion trapping, mass spectrometry, high-vacuum technology, and facilities developed originally for other disciplines are making new experiments possible in atomic collisions and plasma physics over a broader energy range.

Gravitational physics focuses on the consequences of Newtonian and post-Newtonian theories of gravity, especially general relativity. During the past decade, outstanding experimental groups began to migrate into gravitational research, bringing new and powerful technologies from other fields. One of the exciting basic research challenges facing physics is the detection of gravitational radiation. During the coming decade, efforts to develop gravity-wave detectors will mature, causing a major transformation of both the tools and results in this field.

Finally, theoretical physics is the framework for elementary-particle, nuclear, and atomic physics. Two of the four fundamental forces of nature, the weak and electromagnetic forces, were united through gauge theories. Attempts to add a third (the strong) force, producing a grand unified theory, have led to the profound prediction that the pillar of the universe's stability, the proton, is unstable.

Theorists hope to join the gravitational force to the other three; they are exploring the possibility that the very high energies, where the forces become unified, can be probed by looking for astrophysical evidence of events at the origin of our universe.

Some recent results in NSF-supported physics work are highlighted in the pages that follow.

Quarkonium and Gluonium

One of the simplest systems for investigating the nature of the strong force is a bound state of a heavy quark and its antiquark, often referred to as quarkonium. During the last several years, exciting results in high-energy physics have come from studying quarkonium at the Cornell Electron Storage Ring (CESR) and also from using a large detector called the Crystal Ball. The latter has been at the Stanford Linear Accelerator Center but moved during 1982 to DORIS, a higher-energy storage ring at the Deutsche Elektronen-Synchrotron in Hamburg, Germany.

The fundamental forces of nature—classified according to their relative strengths—are gravitation, the weak force, the electromagnetic force, and the strong force. Recently, the weak and electromagnetic forces have come to be recognized as one, called the electroweak force. The strong force, mediated by particles called gluons, binds together the fundamental building blocks of matter—the quarks.

The nuclear particles—mesons such as pions and baryons such as protons and neutrons—are composed of quarks. The common quarks—up, down, and strange—were joined in 1974 by a fourth called charm, which had been hidden in a newly discovered particle called the psi (a bound state of a charm quark and its antiparticle that is sometimes referred to as an example of charmonium).

In 1977 a particle called the upsilon was

A Crystal Ball. Researcher assembles the Crystal Ball detector, formerly at the Stanford Linear Accelerator Center in California and now located in Hamburg, Germany. In recent years the use of this detector—an array of 730 sodium-iodide crystals arranged symmetrically around a central hole—has produced some exciting results in high-energy physics. A key feature is the precision with which the Crystal Ball measures the energy and direction of a photon (a small quantity of radiant energy).

discovered at the Fermi National Accelerator Laboratory in Batavia, Illinois. Later this particle was interpreted as a bound state of a new heavy quark and its antiparticle. This new quark was named bottom, and the upsilon was the first example of bottomonium.

Charmonium and bottomonium states are mesons and thus are similar to lighter mesons such as the pion, which is also composed of a quark and antiquark. An important difference is that in pions the binding energy of the quarks is large compared to the quark mass, whereas for the psi and upsilon the reverse is true. As a result, the quarks inside a pion move at speeds close to that of light and must be treated relativistically.

The complications of the theory of relativity can be ignored in considering the states of charmonium and bottomonium where the quarks move more slowly. Indeed, a rich spectrum of states has been predicted, with transitions taking place from those of higher energy to states of lower energy with emission of a photon. In this way quarkonium is similar to the simple hydrogen atom or to positronium, a bound state of an electron and positron. Similarly, studies of quarkonium are revealing the nature of the interquark, or strong, force.

Transitions from one charmonium state to another with emission of a photon have been observed, most of the exhaustive data coming from experiments using the Crystal Ball. The important feature of the Crystal Ball is the precision with which the energy and direction of the photon are measured.

In 1982 the first evidence for a bottomonium transition was observed at Cornell, using a device called the Columbia University-Stony Brook (CUSB) detector. Cornell's electron storage ring has the optimum energy range for producing bottomonium, and the Crystal Ball should be able to observe other bottomonium transitions.

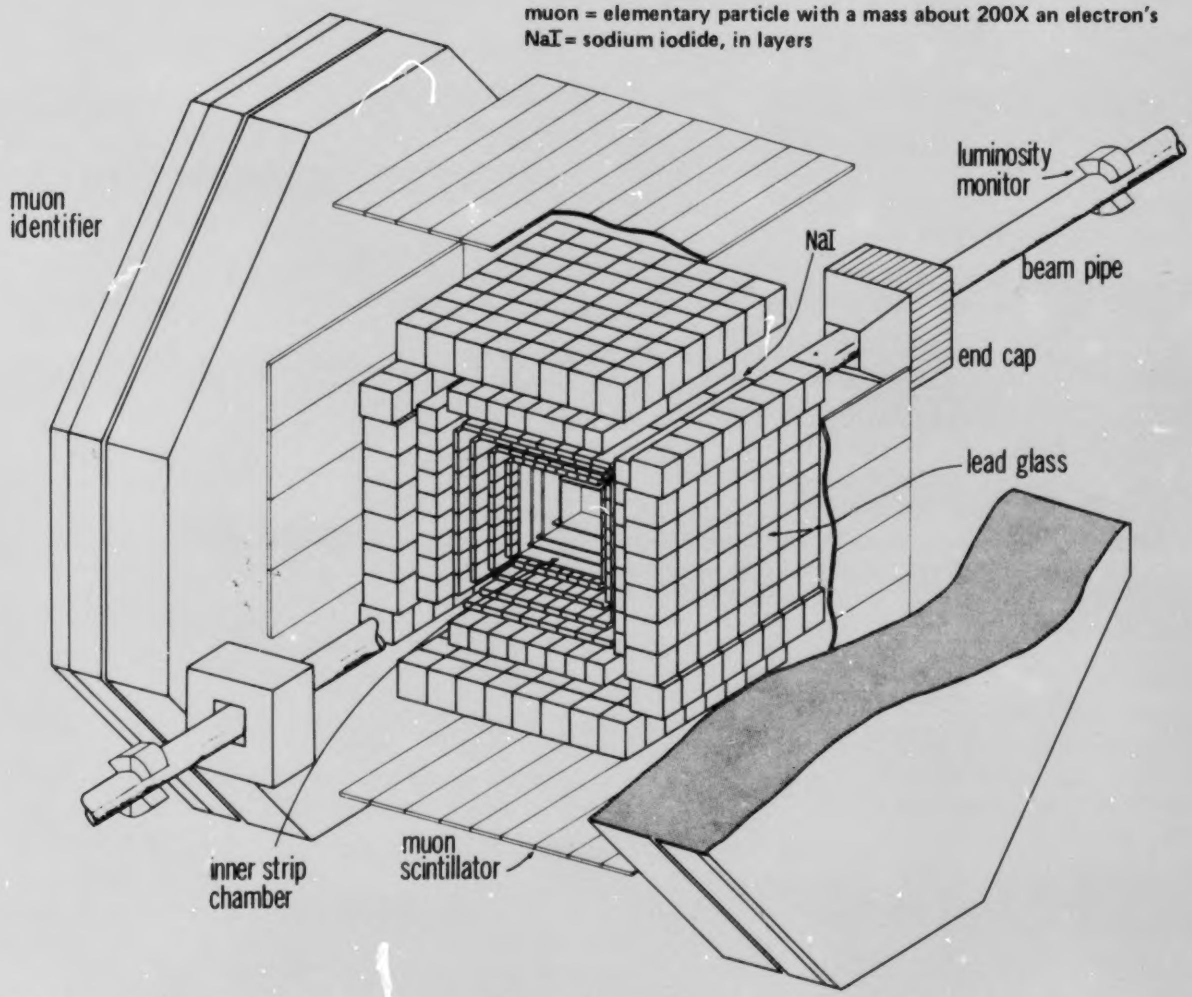
Finally, although the interest in quarkonium has been based on the close parallels with positronium, there is one way in which the strong force and electromagnetic force differ. Whereas photons—the carriers of the electromagnetic force—cannot form bound states with each other, gluons—the carriers of the strong force—can and are expected to do so. Bound states of gluons are called glueballs or gluonium.

A spectrum of gluonium is expected. Recent data from the Crystal Ball have revealed two strong possible candidates for gluonium: the iota and theta particles. These states were observed in psi decays and were accompanied by a photon. Much more data are needed before more definitive statements about the glueball nature of these new states are possible. At this writing, though, the prospects are good.

Some Implications of Spontaneous Decay

Almost every particle or conglomerate of particles existing in nature is unstable on some time scale. Apparently without requiring any external perturbations, excited atoms emit photons and pass to lower energy states; nuclei and molecules split up into constituent parts; and elementary particles decay into some set of other elementary particles, most of which will in turn undergo further decay. Despite the fact that these different systems decay via quite different mechanisms, they all appear to do so with the same type of time dependence: The probability per-unit-time of a decay is constant, with the value of the constant depending on the system being studied.

Our best understanding of this process comes in systems, such as atoms, where the process is electromagnetic in origin. In that case, the theory of quantum electrodynamics (QED) can be used. QED does tell us that



muon = elementary particle with a mass about 200X an electron's
NaI = sodium iodide, in layers

CUSB detector. A schematic view of the Columbia University-Stony Brook detector shows that it is essentially split into four quadrants. This detector, along with Cornell University's electron-positron storage ring and the Crystal Ball described earlier, is an example of the modern instrumentation that scientists increasingly rely on for advances in their work.

unstable particles can decay with the simple time dependence that is observed. However, QED also indicates that many other types of time dependence should be possible.

Since no other type of decay has ever been observed, it is possible that some aspect of the QED theory of spontaneous decay is incomplete or incorrectly understood. Because QED is used as a model for theories of weak and strong interactions, and because systems that decay via those interactions (nuclei and elementary particles) seem to do so in a parallel fashion to atoms, it is important to understand more fully the implications of the QED theory of spontaneous decay.

Even more generally, spontaneous decay is an aspect of one of the central concerns of modern physics—the study of irreversible processes. There are intimate connections between the elementary decay process and thermodynamic irreversibility, but in general these connections have never been tested experimentally.

Fundamental experiments on spontaneous decay are hard to carry out. The decay results from an interaction of the atom (molecule, etc.) with the electromagnetic vacuum, and researchers generally have felt that the characteristics of the vacuum could not be altered. In 1982, however, Daniel Kleppner and his associates at the Massachusetts Institute of Technology showed experimentally that the electromagnetic vacuum can be altered, opening a whole new area of research in spontaneous decay.

This new work is based on the known fact that a cavity can alter the distribution of photon states from its free field value. For example, an atom in a cavity having a broad-band response to the atomic decay frequency should decay more rapidly than a free atom. And an atom in a cavity that does not respond to the decay wavelength of the atom should not be able to decay.

The difficulty until recently has been that cavities could not be built to respond to frequencies corresponding to likely atomic decays. However, increasing sophistication in the production of high excited states of atoms has made it possible to find very probable atomic decays at wavelengths where highly-tuned cavities can be produced.

Using this technique, the MIT group has been able to show inhibited absorption of radiation, which theoretically implies the existence of inhibited decay. Future work will be directed toward efforts such as (1) direct observation of inhibited, and eventually forbidden, spontaneous decay and (2) a transition of the generally irreversible decay process into a reversible one when only a single cavity mode interacts with the atom.

Detecting Gravity Waves

Gravitation was the first physical force for which a fundamental theory in the modern sense was developed. Isaac Newton described gravitation as an action-at-a-distance force exerted between pairs of masses and having no independent dynamical degrees of freedom. For almost two centuries Newton's theory was the paradigm for developing theories of other physical phenomena.

Toward the end of the last century, James Clerk Maxwell, building on Michael Faraday's experiments, developed a unified theory of electromagnetic phenomena. To do this, he had to abandon the previous mode of description and use a new one. In this new manner of expressing physical phenomena, force fields acquire independent dynamical degrees of freedom that can transport energy, momentum, and angular momentum through the vacuum with a definite velocity, that of light. This theory not only unified the description of electrical and magnetic phenomena but ultimately encompassed the physics of optics, radio, x-rays, gamma-rays, and chemical valence forces, among others.

In 1905 Albert Einstein concluded that Newtonian mechanics had to be revised. But the idea he developed, now known as special relativity, was not compatible with Newton's formulation. The general theory of relativity, which Einstein published in 1916, incorporated the successes of Newtonian gravitation theory with regard to the motion of the planets. It predicted, however, three subtle deviations: a slight deflection of starlight as it grazes the sun, the precession of the perihelion of planet Mercury, and a shift to the red of the spectral frequencies of light emitted by atoms on the surface of the sun. All three effects were observed and are as predicted by the new theory.

Until recently, one novel feature of the new theory of gravitation has been largely unexplored: that the relativistic gravitational field must have independent dynamical degrees of freedom which can propagate energy, momentum, and angular momentum through the vacuum. Gravitational radiation must exist, but formidable technological obstacles have impeded the observation of this effect. To observe the gravitational radiation produced by the explosion of a supernova in our galaxy, it would be necessary to detect the motion of one end of a meter-long aluminum bar to an accuracy of better than one-ten thousandth of the radius of a proton.

Groups at Stanford University, the University of Maryland, and Louisiana State University expect to attain such inconceivable accuracy in 1983. There is also an expectation that, within the next several years, detection devices under development at the California Institute of Technology and the Massachusetts Institute of Technology will be able to observe motion no larger than one-millionth of the radius of a proton. This will open a new astronomical window on the universe, since gravitational radiation can penetrate the dust-filled regions of galactic nuclei—which are impenetrable to light.

Monopole-Catalyzed Nucleon Decay

Grand unified theories, which try to unify the basic forces of nature, predict a number of exotic phenomena. One of these is nucleon decay—the spontaneous disintegration of a proton or neutron in an atomic nucleus into lighter particles. These would include electrons or related particles. Nucleon decay, for which numerous experimenters throughout the world are searching, would tend in the long run to the dissolution of the universe as we know it, since all nuclear matter would cease to exist.

Another striking prediction of grand unified theories is the magnetic monopole—a particle surrounded by a magnetic field that decreases with distance from the center of the monopole. The monopole is a magnetic analog of the familiar electric point charge, which is surrounded by an electric field that decreases with distance from the charge. While particles which are approximately point charges abound in nature, no magnetic monopole has ever been definitely observed. However, excitement has been generated by the possible observation of such a monopole by Blas Cabrera in a Foundation-supported experiment at Stanford University in 1982.

A recent discovery is that the magnetic monopoles predicted by grand unified theories should act as catalysts for nucleon decay. That is, when a monopole strikes a proton or neutron, it should cause that particle to disintegrate instantly. A monopole, passing through a large detector in which the infrequent unassisted nucleon decays were being sought, would suddenly cause a whole string of such disintegrations in nucleons about one foot apart. This prediction is based on theoretical work by V. Rubakov in the Soviet Union and NSF-supported research by Curtis Callan at Princeton University. Related important work on monopoles has also been done by Frank Wilczek at the NSF-supported Institute for Theoretical Physics, University of California, Santa Barbara.

All this research has shown that the two striking predictions of grand unified theories—magnetic monopoles and nucleon decays—are actually related. It has also opened our eyes to the extremely rich structure of the magnetic monopole. Close to its center, this monopole possesses not only a magnetic field but a complex cloud consisting of exotic forms of matter and energy. It is this rich, complex structure at its core that enables a monopole to catalyze nucleon decay.

Chemistry

Chemical reactions involve the change of one substance into another. Such changes are fundamental in every aspect of our lives, from the way our bodies sustain us to mechanisms for manufacturing industrial products. Nearly every mixture of chemicals can react in diverse ways to yield several different products. The power to control the outcome of a chemical reaction—a vital concern in all areas of chemistry—involves the ability to manipulate the possible reaction pathways.

The conflicting needs involved in generating a reasonably rapid but specifically selective chemical reaction produce some of the most important demands on the chemist's expertise. This is true whether the area is catalysis, photochemistry, electrochemistry, theory, or any of a multitude of disciplines that make up the field.

Recent advances have improved both the specificity and speed of many catalytic reactions. Manipulation of chemical reactivity to achieve the isolation and separation of new materials with almost any conceivable predetermined property is coming closer to reality. This is a result of progress in metal complex-ion catalysis and in new experimental techniques such as photochemistry (including laser selective photochemistry).

New abilities to determine the composition and structure of solid surfaces have generated knowledge that can be applied to heterogeneous catalysis. It is in this area that most practical applications can be anticipated. Light can also be used as a chemical reagent or catalyst either to open or to block specific reaction pathways. Recent advances in laser capabilities have enabled chemists to increase their abilities greatly in this area.

Many reactions can be controlled by electrochemical means. The ability to obtain reaction specificity by altering an electrode surface has recently opened a spectacular array of chemical possibilities. The combination of light absorption and electrochemistry is another active area of research with tantalizing applications to solar energy.

A critical aspect of manipulating chemical reactivity is the increased theoretical understanding of reaction mechanisms and rates. There are now accurate models to predict the energies of molecules in the course of a reaction and their motion along reaction paths; this has enabled chemists to predict confidently how to control reactions. It has also provided a framework for the interpretation of experimental results. Continued experimental and theoretical research into the precise details of reaction paths will further our abilities to control the course of chemistry.

Catalysts from Clay Minerals

For millennia people have used clay minerals to manufacture useful products, and the potential of clays is apparently far from exhausted. Two Michigan State scientists are incorporating homogeneous catalysts into clays, which may become useful in the manufacture of fuels, drugs, and other chemicals.

The Michigan State researchers—chemist Thomas J. Pinnavaia and soil scientist Max Mortland—are studying the reactivity of metal ions on the intracrystal surfaces of clay minerals. The swelling clays known as smectites are most easily modified by metal ions to form useful catalysts. Early experiments have shown that solvated metal ions on clay mineral surfaces can be as mobile and reactive as metal ions in solution. This initial discovery makes it possible to do solutionlike reactions in the solid state and eliminate a host of problems associated with soluble catalysts.

Fixed catalysts—those in the solid state—generally are preferred over catalysts in solution in large-scale industrial reactions. They are easier to handle and require less expensive capital equipment. But the drug L-DOPA, useful in the treatment of Parkinson's disease, is now manufactured using a solution-phase rhodium catalyst. By binding the rhodium compound to clay surfaces, the Michigan State scientists can easily recover the precious metal so it can be used over and over again.

By fine tuning the structures of clays, the reactivity of metal ions on clay surfaces can be modified and structures can be tailored so that only molecules of a certain size or shape can come in contact with these catalysts. Size or shape specificity is the key to designing new, more efficient catalysts for chemical processing. Recently, Pinnavaia and Mortland have used metal-ion clusters as molecular pillars between the clay sheets. The clusters expand the clay and expose the large internal surface area of the minerals. By controlling the size and spacing of the pillars, the scientists can manipulate the size of the pores in the clay structure; they can then get pores larger than those afforded by conventional petroleum-refining catalysts.

Use of pillared clays for catalytic reactions of large petroleum molecules is of considerable interest, since most of the larger molecules in petroleum go unrefined for lack of suitable catalysts, ending up as asphalt or low-grade fuel. Through the use of pillared clays, apparently even the larger molecules can be converted to more useful high-energy fuels and petrochemicals.

It also seems possible that through future experimentation pillared clays may be used as dispersing agents for agricultural chemicals. When applied directly to soil, some pesticides rapidly decay or wash away, with only a small percentage of the pesticide being effective in controlling weeds or insects. By stabilizing pesticides on pillared clays it is possible to control their release into the environment and make them more efficient.

Photochemical Reactivity

Chemical reactions caused by light (known as photochemistry) have been studied for many years; however, the deliberate design of molecules that can change their geometries and reactivities when exposed to light of a particular color is new. When light energy is absorbed by a molecule, a more energetic molecule is produced in what is known as an "excited state." If the molecule is properly designed, it can then put that energy to good use.

Jeffrey I. Zink at the University of California, Los Angeles has come up with a new method of using light to alter the geometries and reactivities of inorganic molecules. One of the exciting new developments reported by Zink's group is the production of an efficient catalyst using light. The precursor to this catalyst is a metal compound with nitric oxide bonded to it.

The most important results were obtained using molecules which, in the absence of light, have a linear bond between the metal and the nitric oxide. The UCLA group reasoned that after light is absorbed, the geometry would change to produce a bent bond between the metal and the nitric oxide. The linear form of the molecule is relatively stable and can be stored for long periods of time; however, the bent form, which is produced by the light, is very short lived (less than one-millionth of a second) and very reactive during its short lifetime.

The key to the design and use of this molecule as a photocatalyst is that after reaction, the short-lived species returns to its original, linear form. It is then ready to absorb more light, become reactivated, and carry out the new reactions.

In the most important study, the catalyst was dissolved in cyclohexene under one atmospheric pressure of hydrogen gas. When the mixture was irradiated with visible light, the hydrogen gas reacted with cyclohexene to produce cyclohexane. This reaction is not observed in the absence of either catalyst or light. More than a thousand molecules of cyclohexane are produced before the metal catalyst is destroyed by a competing side reaction.

The overall goals of the UCLA researchers are to develop the theoretical rules that govern photochemical reactions and apply them to important chemical problems. The short-lived species produced when light is absorbed have new properties, and the reactions they undergo are governed by new rules. In the case of photohydrogenation catalysis, the theory of the geometrical distortions and the resulting new properties were derived. Using the theory as a guide, the team designed molecules to carry out the predicted new reactions. Developing the rules of photoreactivity and designing new systems to carry out important reactions (including solar energy conversion and storage) present exciting areas for future research.

New Chemical-Reaction Pathways with Lasers

The availability of intense laser radiation (power density greater than a million watts per square centimeter) has opened the door to a wealth of new and exciting chemical phenomena. One class of such phenomena deals with kinetics and the rates at which chemical reactions occur. Chemist Thomas F. George of the University of Rochester and his coworkers have suggested that intense laser radiation can interact directly with the dynamics of a chemical reaction to alter reaction pathways or create new ones, leading to products that are inaccessible in the absence of radiation. It is especially significant that the energy of the radiation not be restricted, so it must be tuned to the energy levels of reactants or of products.

With NSF support, George and his research group have theoretically explored the feasibility of a variety of laser-induced chemical rate processes. These processes include energy transfer, simultaneous bond breaking and bond formation, and ionization in gas-phase molecular collisions. While most of the laser-induced processes involve the absorption of radiation by the chemical system, some do not; hence the radiation can be viewed as a catalyst—it is recovered in the same amount after the reaction is over.

Two specific effects of the intense radiation on a chemical system are worth noting. First, the radiation can change what are known as "symmetry rules" that govern the course of a reaction. The reason for this is that the radiation enables the chemical system to change its angular momentum in a way that is often difficult or even impossible without the radiation. Second, the radiation can lower potential energy barriers to certain sets of products, opening new reaction pathways.

One of the processes studied is the reaction of fluorine atoms with hydrogen molecules to form hydrogen fluoride (HF). This is the reaction used as the basis of the HF chemical laser; most of the hydrogen fluoride is formed in its second-excited vibrational level, and lasing results when those molecules release energy to drop to their most stable ground state. By shining light from a neodymium:glass laser on the reaction system, where the radiation is not resonant with either the reactants or the products, it is possible to alter the reaction so that the third-excited vibrational level of the molecule is more populated. This has interesting and potentially useful consequences for the mechanism and character of the HF chemical laser.

Recent laboratory experiments seem to have confirmed some of the general predictions made at Rochester. Research must still concentrate on the simple systems of several atoms in order to understand fully how the intense radiation interacts with chemical reactions. But eventually the mechanism of some reactions involving large (e.g., organic) molecules may be controlled by illuminating their reactions with light of the appropriate color.

Chemically Modified Electrodes

Recent research on chemically modified electrodes has been done by Royce W. Murray of the University of North Carolina, Chapel Hill. Murray has developed the chemistry for preparing modified electrodes and has given us many examples of how innovative basic chemical research has potential technological significance.

Chemically modified electrodes are conductors coated with thin films of electron-transfer reagents. When such an electrode is used in an electrochemical cell, the reagents can rapidly exchange electrons with the underlying electrode as part of the cell reaction.

In the last year Murray has carried the predictive-design concept of chemically modified electrodes a step further. He has prepared electrode surfaces that bear polymeric films of electron-transfer reagents (redox polymers) with known electron-energy levels. Moreover, those films are arranged in special physical structures. These spatially structured electrodes include bilayers of films, extended area electrodes, and ion gates.

A bilayer electrode is prepared by first coating the electrode with a thin (50 to 500 angstrom), pinhole-free film of one redox polymer and then with a film of a second redox polymer, which has its electron energy levels at a selected different potential. In an electrochemical cell, the junction between the two polymer films acts to rectify the flow of electricity, just as a semiconductor does. The discrete but different electron-energy levels of the two redox polymers act to effect irreversible charge flowing as the "bent" bands of a semiconductor junction do. The redox polymer films are narrow-band (redox) conductors; as Murray has pointed out, this is a distinctive form of electrical conductivity.

Another physically structured, modified electrode designed by Murray and his coworkers is the extended-area electrode. An important and widely researched application of modified electrodes is for electrocatalysis. In this application, the surface-immobilized electron-transfer reagent catalyzes the exchange of electrons between the electrode and the substrate molecule dissolved in the contacting solution. Such electrocatalysis has importance in solar energy conversion, electrosynthesis, fuel cells, and electroanalysis.

Rather thick films of the polymeric electrocatalyst on the electrode are desired, for several reasons. However, such thick films limit the achievable rate of electrocatalysis, due to the need to transport electrons through the redox polymer film via the electron levels. The extended-area electrode solves this problem by incorporating a large quantity of broad-band conducting particles (carbon) into the redox polymeric film. The carbon provides "bridges" for rapid electron flow to the outermost reaches of the redox polymer film.

The ion-gate electrode is a redox polymeric film poly(pyrrole) with a porous (gold) electrode embedded inside. Poly(pyrrole) has a very low conductivity to the flow of ions in the reduced redox state, plus a high conductivity when oxidized. With the redox polymer film used as a membrane separating two salt solutions, the membrane's conductivity can be turned off and on externally by controlling the poly(pyrrole) oxidation state with the embedded electrode. There is no known manmade counterpart to this membrane arrangement, which may serve as a model for studying biological membranes.

Materials Research

At some point in the evolution of most technological developments, we must consider the limitations of materials—their processing, properties, and performance. Materials research, a multidisciplinary activity, provides the scientific basis for long-term understanding and resolution of these limitations.

The technological challenge of this research is diverse, covering many important opportunities. These include semiconductor devices for the electronics industry, high-temperature structural metals and ceramics for heat engines, high field superconductors for magnets, and the burgeoning area of polymers for many industrial uses. The field is correspondingly broad, involving physics, chemistry, metallurgy, ceramics, polymer science, and engineering (chemical, mechanical, and electrical).

Materials research is also at the forefront of major conceptual advances in scientific understanding, including universal principles of phase transitions, the nature of the amorphous state, and the behavior of low-dimensional systems (such as surfaces, interfaces, layered materials, and one-dimensional conductors).

NSF fosters interactions among several disciplines through:

- *Scientific Research Project Support*—Eight programs in solid-state physics, solid-state chemistry, low-temperature physics, condensed-matter theory, metallurgy, polymers, ceramics, and instrumentation for materials research.
- *Materials Research Laboratories*—Block grants to 14 universities for interdisciplinary materials research.
- *National User Facilities*—Synchrotron radiation at Stanford, Cornell, and Wisconsin (Madison); the National Magnet Laboratory at MIT; and the National Center for Small-Angle Scattering Research at Oak Ridge, Tennessee.

In the last decade unprecedented developments in materials research have occurred on three fronts: innovative synthesis and processing of new materials, new high-resolution experimental techniques for the study of structures and properties, and powerful new techniques for theoretical analysis and modeling. These have profoundly affected the development of basic materials science and have done much to unify the field.

Recent advances in synthesis and processing of materials include:

- Synthetic polymers that conduct electricity.
- Glassy metals with low magnetic hysteresis.
- Semiconductors with extremely low defect concentrations and hence improved electrical properties.
- Compositionally modulated alloys having unusual elastic moduli.
- Surface modification by laser annealing and ion implantation.
- Ultra-strong polymer fibers.
- Ceramic powders synthesized from polymers, organometallics, and inorganic solutions.

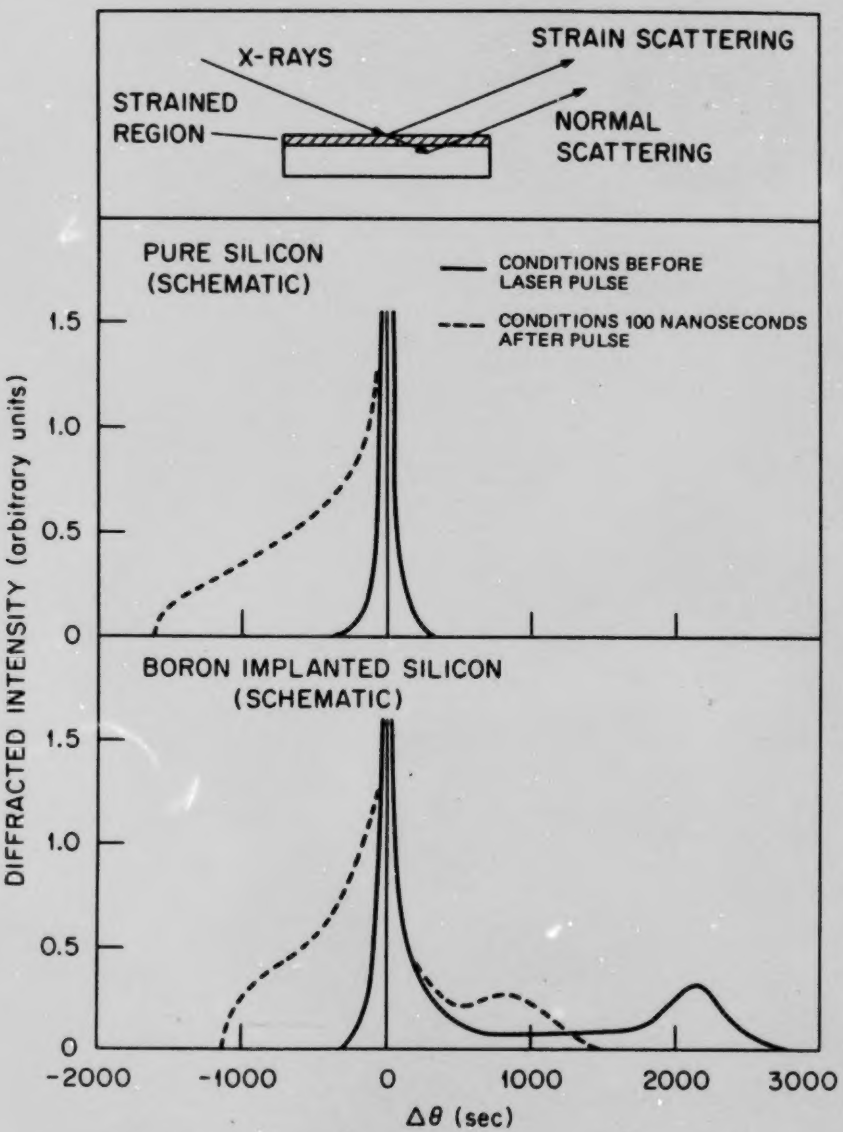
Advances in sophisticated instrumentation now make it possible to image the configuration of atoms and clusters of atoms by high-resolution electron microscopy and to determine their chemical composition by electron energy-loss spectroscopy. Then too, the interaction of electron beams, ion beams, or molecular beams with surface atoms can be used to probe the chemical composition of surface monolayers. Structural rearrangements at surfaces under varying conditions can be followed with high-intensity, monochromatic x-ray and ultraviolet light from synchrotron radiation sources; the bonding of atoms to a surface can be measured by electron- or photon-stimulated desorption. Finally, extremely short pulsed x-ray and laser radiation allows scientists to follow time-dependent changes.

In the realm of theoretical analysis and modeling, quantum mechanical calculations of electronic structure have shed new light on structural transformations in metallic alloys and semiconductors. Theories based on renormalization group transformations have given researchers a unified insight into various phenomena such as phase transitions in spin-glasses, liquid crystals, polymers, and absorbed surface layers. Other theories have contributed to the understanding of nonlinear phenomena in such diverse systems as liquid helium, organic conductors, and charge-density waves.

Ultrafast X-Ray Structure Determination

The advent of pulsed sources of high-intensity synchrotron radiation has now made it possible to do x-ray studies of the structure of matter on a time scale not attainable before. In one such effort, scientists from Oak Ridge National Laboratory and the Cornell High-Energy Synchrotron Source (CHESS) have used the unique CHESS features to study the laser annealing of silicon crystals on a nanosecond scale. A nanosecond, one-billionth of a second, is very short compared to the time scale for the diffusional motion of atoms involved in the structural rearrangements of silicon. Thus it is possible to obtain "snapshots" of the events taking place during laser annealing.

In these particular experiments by Bennett Larson, Woody White, and Thomas Noggle of Oak Ridge in collaboration with Dennis Mills of Cornell, the laser is triggered by a monitor pulse from the synchrotron. The laser pulse then irradiates the silicon sample at a desired time interval before the x-ray pulse arrives. The intensity of the x-ray pulses (approximately 25,000 photons in each) is great, the burst is very



X-ray snapshots. Through modern x-ray techniques, scientists can now study the structure of matter on incredibly short time scales. This diagram shows what can happen when laser pulses are applied to silicon crystals—both pure and boron implanted—on a nanosecond scale, or one-billionth of a second. The distortions induced by thermal strain correspond to a surface layer temperature of 1150 degrees centigrade. (At one point the silicon even reached its melting point of 1410 degrees.) This work has key applications in fields other than materials research—for example, in fabricating ultrasmall microelectronic devices.

short (160 picoseconds), and the interval between them is long enough (2.5 microseconds) that a snapshot can be obtained. A multichannel analyzer records the intensity of the scattered x-rays.

Results of these experiments agreed qualitatively with the changes expected. When the team analyzed those results in terms of thermal expansion, it could obtain a determination of the lattice temperature. At 100 nanoseconds after the laser pulse, the lattice temperature was about 1150 degrees centigrade. At shorter times, just after the laser pulse, the lattice temperature increased to the point where it reached 1410 degrees, the melting point of silicon.

The question of lattice temperature and whether or not melting occurs during the laser annealing of silicon has been the subject of an ongoing controversy, but the scientific issues involved have been much clarified by these experiments.

The significance of the experiments is twofold: First, they demonstrate the feasibility of using the fundamental tool of x-ray diffraction for determining structures on extremely short time scales. This is expected to have widespread application in studies of phase transitions and nonequilibrium properties of matter. Second, laser annealing has potential for important applications in the fabrication of ultrasmall microelectronic devices used in the computer and information technologies. But more understanding of the processes involved in laser annealing of silicon is necessary for the technique to be implemented in technology.

Pump and Probe: Optical Studies of Ultrafast Processes in Matter

Advances in time-resolved laser spectroscopy over the past 20 years have led to remarkable improvements in our ability to probe the properties of matter on increasingly shorter time scales. In the 1960s, the limits were on the order of microseconds (one-millionth of a second, or 10^{-6} second). In the early 1970s limits were reduced to the nanosecond (10^{-9} second) range, and recent advances have shortened the time scale to a picosecond, or trillionth (10^{-12}) of a second.

Researchers at Bell Laboratories and Cornell are now able to produce laser pulses with a resolution of a few tens of femtoseconds (10^{-15}). The early pulse lengths permitted scientists to excite solids and study the relatively slow recombination of electrons and holes in semiconductors. The latest ultrafast laser techniques open the door for observation of much faster processes, such as vibrational and rotational relaxation in molecules.

In the past year, Chung L. Tang and his colleagues at Cornell University have done the first measurements of molecular relaxations in liquids. The particular experimental method used is called "pump and probe." In it, a short, intense beam of laser radiation is used to excite or "pump" matter. A second weaker beam, split off from the first and delayed by a short time (less than a picosecond), is used to detect or "probe" the changes induced by the excitation.

By varying the delay time, it is possible to measure the rate of relaxation, from which the mechanism can be analyzed. In Tang's case, the pump pulse served to orient rodlike molecules of liquid carbon disulphide (CS_2) in the normally isotropic liquid. The probe pulse detected the change in the optical index of refraction originating from the molecular alignment and followed its decay with time.

Two decay rates were observed, corresponding to different relaxation mechanisms. The first, more rapid decay signals the equilibration of a given orientation; the second, slower decay signals the equilibration to an isotropic liquid. Whereas the slower decay mode had been inferred from other types of measurement, the rapid one had not been directly observed before.

The facilities required for spectroscopy in the femtosecond regime are expensive and the techniques quite sophisticated; very few universities have the resources to undertake such research. Essential interaction between researchers focusing their joint resources on difficult problems is a characteristic of the Materials Research Laboratory Program and the Materials Science Center at Cornell University. The extension of these high-resolution techniques to a study of the nonlinear optical response of solids is critical in developing new optical materials—particularly glasses for high-energy laser applications and optical switching elements for high-speed data transmission.

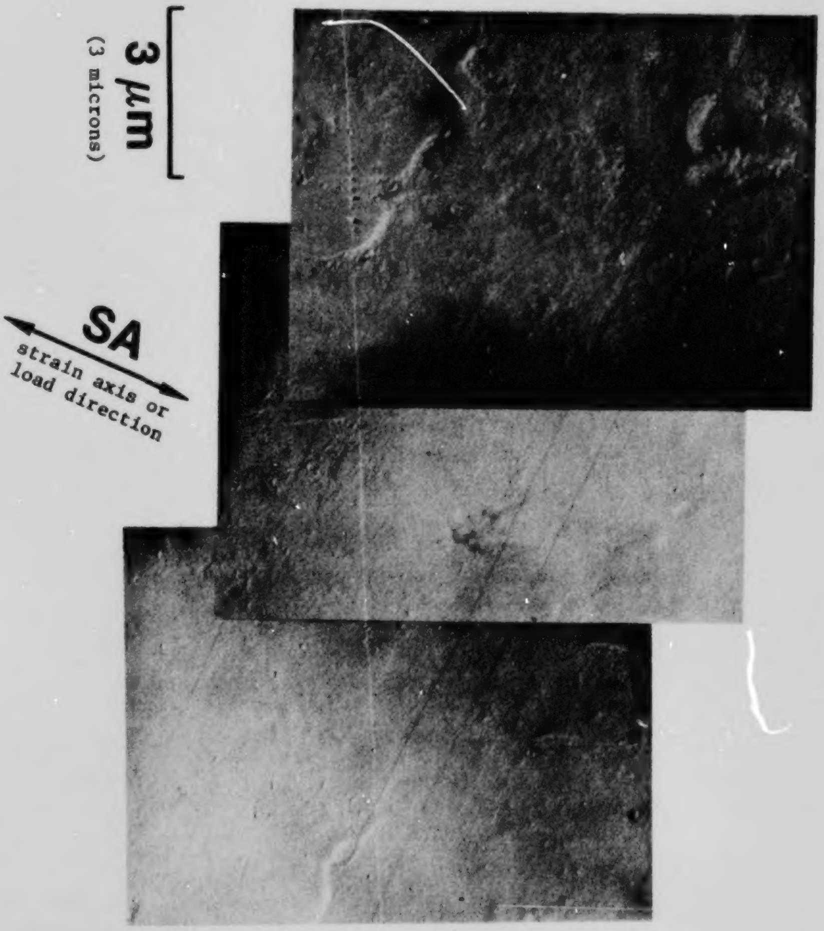
Nondestructive Monitoring of Small Fatigue Cracks

The reliability of structural materials under extremes of stress, temperature, and environment is a recurrent concern of materials scientists and engineers. The engineering approach has been to quantify the fatigue behavior of materials by applying different levels of cyclic stress to small laboratory specimens and observing the number of cycles to failure. Materials scientists are trying to get more insight into what starts fatigue damage and causes cracks to nucleate and progress to fracture.

Studies are now under way throughout the world to gain a better understanding of the nucleation and growth behavior of fatigue cracks. Special attention goes to the development of nonintrusive techniques to monitor growth of microcracks, since researchers have found that during most of the time before a material's fatigue failure, cracks are growing from micrometers to millimeters in size.

Researchers at the University of Pennsylvania and Northwestern University are investigating the early stages of cumulative damage due to cyclic loading. In particular, Campbell Laird at Pennsylvania has successfully related the dislocation interactions observed in single metal crystals to the cyclic deformation behavior in polycrystals. Morris Fine and graduate student Donald Anton of Northwestern came up with innovative methods that allowed them to identify the smallest fatigue-crack nuclei yet seen. Through surface-replication electron microscopy, they detected cracks as small as 0.1 micrometer on the surface of an overaged nickel aluminum alloy after low-level stressing.

As fatigue cracks grow, they dissipate



Cracks—See how they run. Using electron microscopy, scientists at Northwestern University have identified the smallest fatigue cracks seen in materials research at this writing. The photograph shows cracks as small as 0.1 micrometer on the surface of a nickel aluminum alloy. This kind of research will aid scientists and engineers in their continuing search for reliable structural materials.

mechanical energy through the emission of heat and acoustic energy. By the accurate placement of tiny thermistors, Johannes Weertman at Northwestern has been able to measure the magnitude of the thermal energy dissipated locally and to correlate this with the rate of crack growth. Acoustic emission is also used to detect and characterize fatigue cracks during growth. Weertman has identified the distinguishing acoustic emissions associated with both crack propagation and stationary crack behavior. In the past year, Y. H. Pao and Wolfgang Sachse at Cornell University have developed a miniature transducer array that will enable them to locate the source of such emissions with high precision.

In pioneering studies at Stanford University, surface acoustic wave (SAW) techniques have recently been developed jointly by Gordon Kino, Drew Nelson, and John Shyne to provide information about subsurface crack behavior. In their method, surface acoustic waves are launched from a transducer source and reflected at the fatigue crack. The reflected intensity is directly related to the area of the crack and thereby to its depth. It is clear that the depth of microcracks can be monitored with good accuracy using the technique. Furthermore, it is used to measure the stress level at which cracks open and to observe the variation in crack dimension with the cyclic stress.

This research involves faculty from very different backgrounds—metallurgy, mechanical engineering, and electrical engineering—working cooperatively in materials research laboratories to develop new approaches to this troublesome problem. The significance of these new nonintrusive techniques is that they offer unique scientific insights into metal-fatigue mechanisms. Obviously continued development of all these experimental methods will prove extremely useful in future fatigue studies.

The Monte Carlo Machine

Much of the theory of materials properties depends on computer simulations using modern techniques of statistical mechanics. Examples include structural-phase transitions in alloys, diffusion of impurities in solids, and the propagation of cracks.

A significant advance in computational technique comes from three condensed-matter theorists at the Institute of Theoretical Physics in Santa Barbara, California. Postdoctoral associates Robert Pearson, John Richardson, and Doug Toussaint designed and built a special-purpose processor that performs particular kinds of statistical calculations much more rapidly than the fastest supercomputer available. The secret of this greater speed is hardware specialization. Circuit elements are arranged in the processor to solve a single problem over and over.

The first problem "hard-wired" in this way is the Monte Carlo simulation of the three-dimensional Ising model—a mathematical construction that describes the phase-transformation behavior of certain types of magnetic materials and metallic alloys. The Ising model has never been solved exactly in three-dimensions, and recourse must be made to approximation methods such as the Monte Carlo approach.

The method gets its name because of the way it generates answers from averages over random numbers (such as could be generated by a roulette wheel). It is widely used though very time consuming when done by a computer; the random number averages must be performed millions of times.

The significance of the new processor is this: Because of its specialized design, it can perform these simple steps at 10 or more times the speed of the fastest supercomputer, and at a small fraction of the cost. The major advance in developing the Monte Carlo machine (in addition to the fact that it can solve the Ising model) is that it points to a way of doing future computations in many other branches of science.

Engineering

2

In recent years, NSF has become a primary source of support for fundamental research across the entire range of engineering disciplines. The Foundation also works to ensure the strength and flexibility of the nation's academic engineering base.

NSF's Directorate for Engineering emphasizes research that advances our basic knowledge of engineering principles and technologies—research that few private-sector institutions have the resources or incentives to support. Broad and timely contributions to technological innovation and industrial productivity, economic growth and competitiveness in world markets, and national defense are also emphasized.

In fiscal year 1982 NSF's engineering divisions focused on many areas, including but not limited to these:

- *Electrical, Computer, and Systems Engineering*—Intelligent electronic systems, solid-state devices, microelectronics, sensors and imaging systems, automated machine processes, very large scale integration, integrated optics, plasmas and particle beams, special-purpose computer architectures, machine intelligence, robotics, information theory, control-systems methodology, and operations research.
- *Chemical and Process Engineering*—Catalysis, biochemical processes, combustion chemistry, separation processes, particulate characterization, thermodynamic and transport properties, and renewable and nonrenewable materials processing.
- *Civil and Environmental Engineering*—Hydrology, wastewater treatment, structural mechanics, design and siting research, construction engineering, upgrading of earthquake testing facilities, and development of a geotechnical testing centrifuge.
- *Mechanical Engineering and Applied Mechanics*—Turbulence, heat transfer, phase changes, machine systems, optimization of manufacturing processes, high-flux heat transfer, tribology, robotics, nondestructive testing and evaluation, time-dependent and unsteady phenomena, and computer-aided design and manufacturing.

Increasingly, developments in science and engineering cut across the traditional boundaries between disciplines, posing new problems while offering new research opportunities. In November 1981, NSF set up the Office of Interdisciplinary Research in the Directorate for Engineering, to focus scientific and engineering expertise more effectively on problems spanning several fields. The NSF interdisciplinary effort has, as one example, brought together programs that focus on biotechnology and robotics/automated manufacturing. Through OIR, NSF also supports workshops, conferences, and special reports on cross-discipline concerns.

To strengthen the nation's research base in engineering, NSF offers special opportunities to full-time engineering faculty who have never received substantial federal funding. Research initiation grants are awarded on a competitive basis and are used for theoretical and/or experimental research projects in any engineering discipline.

NSF also makes awards for specialized research equipment to improve the quality or broaden the scope of research that an institution can perform. The institution is expected to make a reasonable contribution of its own funds toward the purchase and should use the equipment in a number of different research projects.

Table 2
Engineering
Fiscal Year 1981 and 1982

(Dollars in Millions)

	Fiscal Year 1981		Fiscal Year 1982	
	Number of Awards	Amount	Number of Awards	Amount
Electrical, Computer, and Systems Engineering	465	$23.43	510	$25.68
Chemical and Process Engineering	367	18.45	438	20.27
Civil and Environmental Engineering	385	28.46	425	29.95
Mechanical Engineering and Applied Mechanics	266	16.01	280	17.07
Interdisciplinary Research	—	—	17	.31
Total	**1,483**	**$86.35**	**1,670**	**$93.28**

SOURCE: Fiscal Years 1983 and 1984 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Electrical, Computer, and Systems Engineering

Research in this area of engineering has helped produce devices, technology, processes, electronic systems, and products that touch every American's life. One recent advance is in very large scale integrated (VLSI) circuits, which are used in ultrasmall computers, consumer products, control systems, robotics, communication systems, and for a host of other applications.

Researchers are continually improving VLSI technology, investigating smaller and smaller circuit configurations. In the future they will multiply circuit-packing density so many times that today's small computers may fit on the head of a pin. The new technology and advances in components and devices are a base on which other researchers build new electronic instruments and systems.

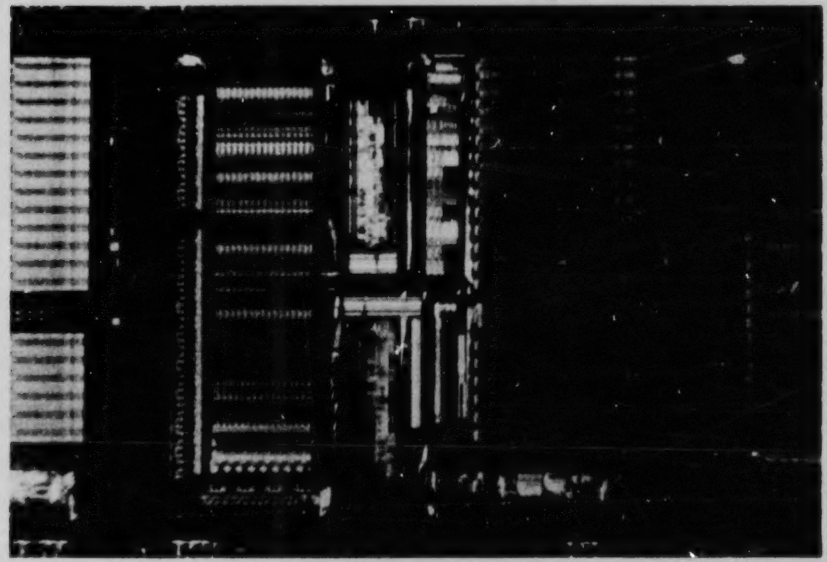
NSF supports research that yields more understanding of electronic microstructures as well as better diagnostic techniques and computer-aided design methodology. New basic knowledge can be applied immediately in areas such as integrated optic systems and hybrid computing circuits. As technology improves, advances follow in knowledge-based systems, robotics, and communications.

Spectacular advances have led to the development of robots that can sense their environments through machine vision systems and touch sensors. Distributed signal-processing modules and computing elements enable robots to analyze data efficiently, producing machine decisions that allow the robots to control and modify their own movements and actions. With this greater flexibility, based on smaller and more effective electronic circuits, robots now have wider potential industrial application.

The information explosion has created an urgent need for faster and more effective transmission techniques. NSF engineering programs support research in advanced communication systems based on various wide-bandwidth, high-capacity approaches. Optical communications via high-capacity, single-mode systems with optical fibers can be improved by adding monolithic integrated circuits using optical devices, semiconductor lasers, and microwave diodes. To yield new knowledge in the communications area, NSF grantees are exploring the technical frontiers of optics, lasers, electromagnetics, and ultrafast networks, as well as multiple modes and digital transmissions.

Also under investigation are remote sensing techniques. Through these, scientists explore millimeter-wave bands and determine the interaction of wavelengths with their surrounding physical matter. In plasma sciences, research continues on novel devices to confine plasmas. Free-electron lasers are another promising area of research.

Scientific and technical advances in materials and devices form the basis for advanced electronic systems and techniques in the field of medicine. Research in these areas will also contribute to dramatic advances in large-scale systems integration and new means of automatic control in industrial processes.



"Super Chip." This "super chip" is a very large scale integrated (VLSI) digital system developed and fabricated by the Hewlett Packard Company. It functions as the central processing unit of a digital computer and contains 450,000 transistors. By 1990, chips with a million transistors will be ready for use. VLSI circuits are expected to be used in products ranging from tiny computers to robots to large control and communication systems. VLSI technology is the foundation for future sophisticated electronic systems.

Integrated Electronic Circuits

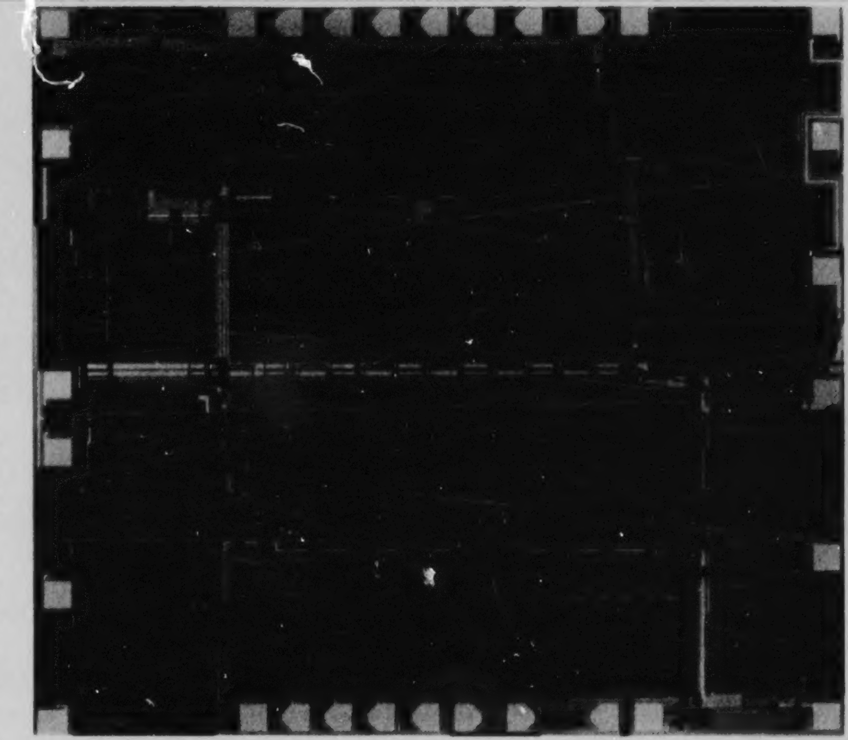
The phenomenal advance of digital integrated electronics in terms of the density of components on a chip has been due largely to improvements in our ability to fabricate ultrasmall transistors. During the 1970s the minimum size or line width in industrial production was reduced from 10 to 2.5 microns. This increased the number of transistors that could be incorporated onto a single chip from 5,000 to 100,000. Through research significant progress continues in digital systems. By 1990 researchers expect line widths to shrink to submicron levels. Chips with a million transistors will then become available for system use.

Many existing physical systems involve both analog (continuous) and digital functions. In voice transmission, for example, it is currently necessary to process basic information in analog form, convert it to digital form for the sake of efficient transmission, then convert it back to analog form at the receiving end for understanding. To do this, systems traditionally have used components such as operational amplifiers fabricated through bipolar semiconductor technology, along with microprocessors and memory components made via metal-oxide semiconductor (MOS) technology. Because the separation of analog and digital functions becomes more cumbersome and costly at higher levels of integration, there is great motivation to fabricate the two functions on the same chip, using the same technology for both functions.

One research group at the University of California, Berkeley has been studying the fabrication, computer-aided design (CAD), and application of integrated electronic circuits and systems. This group has used MOS digital technology first to realize analog functions, then to integrate analog and digital functions. The work began with implementation of analog-to-digital and digital-to-analog converters using charge redistribution on capacitors. This technique has since been used in industry for the integrated electronic implementation of converters for all-digital voice networks.

Further work on operational amplifiers in MOS technology has provided a truly flexible and generally applicable design approved for such analog subsystems as filters, converters, and voltage references.

Industry's translation of university research into fabricated chips is highly desirable from a productivity standpoint; it also leads to new fundamental knowledge through feedback from industry to the university. Recently attention has turned to extending the useful frequency range of monolithic filtering technologies—including switched capacitor techniques—to higher levels, so that these methods can be used in communication receivers. Further research will also focus on basic limitations in monolithic systems to collect data.



Filter chip. This switched-capacitor filter chip is used in digital voice systems and contains 20 operational amplifiers. More than 3 million of these chips are manufactured each year—the product of a successful industry-university partnership in which academic research is translated into fabricated chips by industry. This arrangement aids productivity, allows university researchers to get feedback on their work, and thus leads to more knowledge about the technology.

Estimation and Signal Processing for Spatial Data

Data from different spatial locations at different times typically contain varying types and amounts of measurement noise, extraneous information, and incomplete measurements. Efficient processing of these data is needed to recover consistent and useful information in meteorology, geodesy, topographical mapping, acoustic oceanography, imaging, tomography, and other activities.

Ad hoc techniques used in the past were tailored to specific problems and often inefficient. Thus it has not always been possible to use all available data to obtain the most accurate product or result. The economic impact of inaccuracy can be very high, as in the case of product testing.

Alan S. Willsky and Bernard C. Levy at MIT are focusing on a systematic approach to the optimal and efficient processing of spatially distributed data. Their research results can be divided into three categories. The first deals with data assimilation, i.e., the problem of combining distinct sets of data obtained at different times and locations to obtain one superior product (in this case, a map or picture). An approach has been developed that reflects the fundamental structure common to many problems in updating, combining, and centralizing maps.

The second category involves efficient and sequential computational methods for smoothing, filtering, and extrapolating spatial data. In two-dimensional spatial data, unlike temporal data, there is no natural "causality" to provide an order for processing the data in sequence. Yet this must be done if there is an enormous amount of data to be handled. The sequential computational procedures or algorithms under study are based on the structure underlying the generation of the data. They offer both efficient and optimal recovery of the relevant information from noisy measurements.

The third, and most fruitful, category deals with imaging in random fields based on indirect noisy measurements. The primary application of this research is in tomography, which involves reconstructing the interior of a medium from the measurement of energy that propagates through it along specified straight lines. The best-known current application is in medical x-ray tomography, but there are many other actual and potential uses, including acoustic oceanographic tomography.

Algorithms developed as of this writing

have been based on two critical, limiting assumptions. First, nothing is known about the medium under investigation. Second, essentially unlimited, high-quality measurements can be and are made. In actuality, for many applications the second assumption is false. For example, in medical problems one must limit total x-ray dose as much as possible, but this also limits measurements. In product testing or imaging of the heart, both geometry and cost (in terms of instrumentation and human exposure to radiation) present serious limitations in data collection.

As the amount and/or quality of data is reduced, the better the model of the medium or the desired information incorporated in the algorithm must be. Consequently this research has focused on developing general models for random fields that contain embedded objects. Examples are organs, bones, tumors in human tissues, or flaws or voids in steel whose existence, location, size, and shape are to be estimated from available data.

The resulting algorithms based on these models may characterize the minimum measurement information needed to acquire a certain level of confidence or accuracy. The results also apply to a more general class of problems arising in oceanography and seismic signal analysis.

Chemical and Process Engineering

Chemical processes are the heart of the chemicals industry, which contributes about 8 percent of the U.S. gross national product. NSF is the only federal agency that has a discipline-oriented program to support research on chemical process design. A better understanding of the scientific principles and concepts that guide such design can be translated into capital and energy savings in producing broad classes of substances and materials. Among them: synthetic fibers in our clothing, fuel for our cars, the plastics we have become accustomed to, and pharmaceuticals.

Biochemical engineering, which builds on the rapidly emerging science of recombinant DNA, has drawn much industrial interest. But biochemical engineers must develop a substantial new knowledge base before biotechnology can fulfill its promise. Current areas of research include:

- Reactor designs that discourage the reversion of recombinant organisms to their original types.
- New techniques to separate and purify products and thus bring down the cost of biological processes.
- Design innovations that will boost productivity by increasing the concentrations of microorganisms in bioreactors.

Other research efforts seek new knowledge for nonconventional processing, such as the conversion of renewable resources into materials and chemicals of higher value. Less-recognized chemical processes are also important. For example, separation processes that produce high-purity silica for optical fibers have greatly enhanced our ability to transmit signals in those fibers over great distances. The emerging chemical techniques used to make computer chips have come from the skills developed by chemical engineers and chemists over the past several decades.

Application of In-Situ Extraction in Fermentation Processes

Recent years have seen rapid growth in the use of microbes to produce industrially valuable substances, despite some inherent disadvantages in the fermentation processes used. Now under investigation are ways to increase final product concentration and improve product extraction; this will make fermentation more efficient and therefore less costly.

Common problems associated with the fermentation process include product degradation by the fermentation broth and product inhibition and repression (in which the product stops its own synthesis). Engineering improvements as of this writing have been limited to genetic manipulation of the organism.

One approach to the problem of product inhibition and degradation is to remove the inhibiting metabolic fermentation products from the aqueous broth during the production phase. This process allows concentration of the product formed, which in turn makes eventual purification steps easier.

Henry Y. Wang and his coworkers at the University of Michigan are studying the use of natural adsorbent resins that can be sterilized by steam and act as separating agents. Wang has found that final fermentation product yields can be enhanced by a factor of two to five. When sterilized XAD-4 resin is added to a 14-liter cycloheximide fermentation, the synthesis rate changes. Peak concentration comes earlier than is normal—the concentration of cycloheximide, a commercially important antifungal antibiotic, increased to double that of normal fermentation in Wang's experiment. The final product concentration was dictated by the exhaustion of glucose in the fermentation medium.

Recent experiments have shown that higher antibiotic concentrations can be achieved with proper glucose addition and pH control. Further evidence suggests that this methodology could be used to enhance other fermentation processes, such as ethanol production from renewable resources. The Michigan researchers are cooperating with the Upjohn Company on ways to scale up *in-situ* extraction fermentation processes. Drawbacks such as nonspecific adsorption and resin effect on microbial growth are under investigation. This novel way to increase fermentation productivity may give a new impetus to the biochemical industries.

Accelerated Settling of Suspensions by Adding Buoyant Particles

Many major industrial processes use sedimentation to separate solids from liquids on a large scale. In mining and minerals processing, for example, sedimentation is used in the settling of coal washings and for separating the "red muds" produced during extraction of alumina from ores. The driving force in most sedimentation processes is gravity. The greatest difficulty is encountered in the settling of suspensions with relatively high concentrations of suspended particles, particularly when the particles have a density only a little greater than that of the fluid.

The settling of suspensions requires large equipment and is a notoriously slow process. Any means of increasing settling rates would be of enormous benefit in reducing the size (and liquid demand) of new settling agents and increasing the handling capacity of existing ones.

Ralph H. Weiland at Clarkson College is collaborating with Charles A. Willus of Dorr-Oliver, Inc. in an industry/university cooperative research project. These researchers have discovered that adding buoyant particles to a sedimenting suspension of heavy particles can greatly accelerate its settling process. The three-phase settling process is extremely complicated to analyze from first fluid-mechanic principles. However, Weiland has developed a macroscopic model based on the variational principal of minimum energy dissipation, which indicates broad trends and gives direction to his experiments.

Improvements in settling rates of up to a factor of six times or greater were observed when the researchers added buoyant particles. The presence of those particles had the most pronounced accelerating effect on sedimentation when the heavy particles had a density only a little greater than the fluids. In other words, the addition of buoyant particles helped most when applied to suspensions that would have been the most difficult to settle. Since large-sized buoyant particles are more effective than small ones and since, for reuse, the added buoyant phase must be separated from the fluid, the use of large particles makes separation particularly easy.

Civil and Environmental Engineering

NSF's civil and environmental engineering programs support research in geotechnical engineering; structural mechanics; hydraulics, hydrology, and water resources engineering; and environmental and water quality engineering. In addition, NSF supports both basic and applied research on ways to reduce earthquake hazard. Some of this research deals with how a community adapts to earthquake risk, but most of it focuses on structural safety.

Support has been provided for a geotechnical centrifuge facility under construction at Mountain View, California. The facility, the largest in the western world, will open in January 1983. The centrifuge will be capable of imposing an acceleration of 300 g's on a specimen of three tons. It can be modified to test a 20-ton specimen with an acceleration of 100 g's.

In many engineering situations, it is necessary to change the value of gravity to achieve true modeling of the behavior of materials. Without a centrifuge this is not possible. The California facility will enable geotechnical engineers to construct models of considerable size and to impose an increased "synthetic gravity" on them. The centrifuge will be used at first for research on structures such as foundations and earth dams. Investigators in other areas of engineering will also have access to the facility.

Basic research on structural analysis now concentrates on the optimal design of structures and the use of interactive computer graphics. One topic of particular interest is the active and passive control of deflections in high-rise buildings. Two existing structures that have devices to minimize deflections during high winds are under study at this writing. Efforts are also being made to understand the phenomenon of cracking concrete and the properties of high-strength concrete.

The high probability that a major earthquake will occur in the United States (probably in Southern California) by the end of the century lends urgency to the Foundation's seismic research programs, and to other federal efforts under the Earthquake Hazards Reduction Act. One major effort to find design and construction techniques that minimize structural damage and loss of life during earthquakes is an ongoing U.S.-Japanese research program. A full-scale, seven-story building of reinforced concrete was constructed and then tested to the point of destruction in 1982. A similar structure of steel will be tested in 1983.

Such tests give detailed information on how full-sized structures respond to earthquake simulation. The work should improve methods of using models to obtain performance data at much lower cost. It will also establish the reliability of the behavior predicted by models, compared to that observed in actual situations.

Building codes now in force across the country reflect what engineers have learned about design and construction. However, many standing structures built under older codes cannot resist seismic stress. Existing buildings vary in character and are expensive to modify; often there is little legal or economic motivation for owners to spend money retrofitting them. While the gradual replacement of our building stock over time will reduce earthquake hazard, the threat of property loss and fatalities remains great. The problem of existing buildings that do not meet new earthquake code requirements is under study.

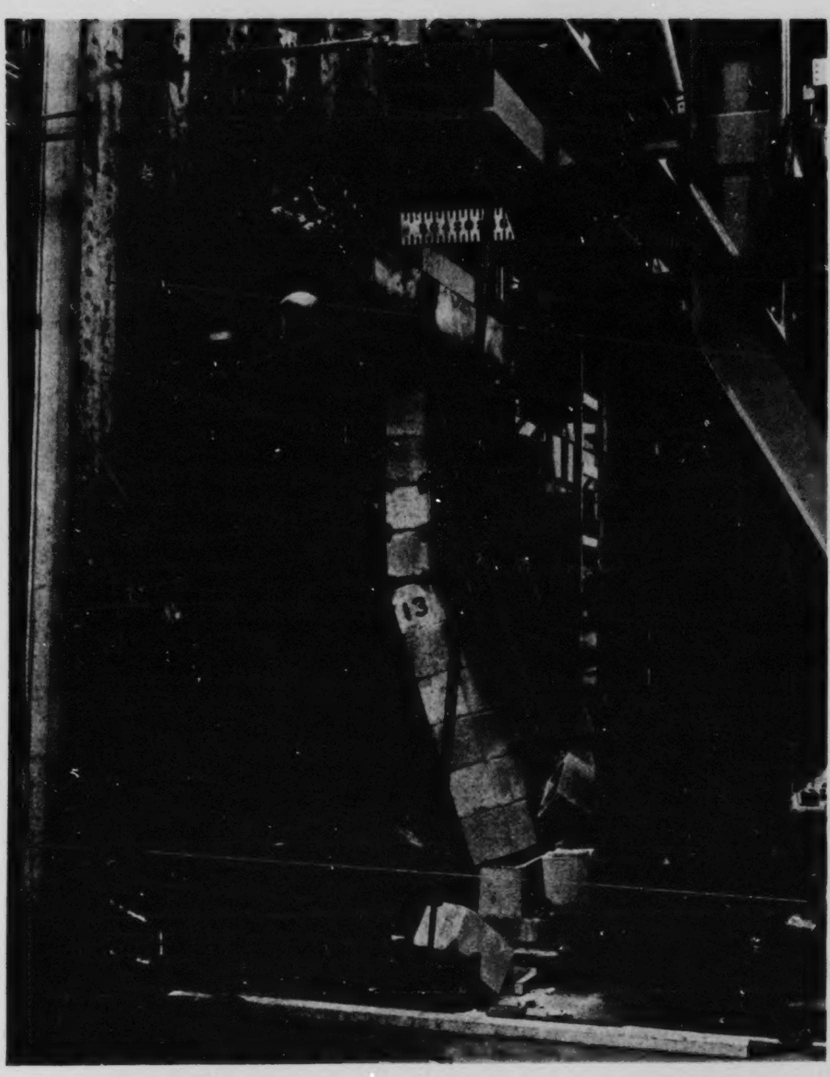
Reduction of Earthquake Hazards in Existing Buildings

Efforts to minimize earthquake hazards aim primarily at design and construction techniques to ensure building safety during seismic events. Analytical approaches are based on detailed knowledge of the strength of materials and methods of construction. Such research has led to rapid improvements in building codes and greater safety in buildings. Still, some estimates suggest that even if present codes are assumed adequate and all new structures are safe, the rate of new construction and replacement is not great enough to affect the overall hazard posed by unsafe, precode buildings.

Technical problems relating to seismic resistance of older buildings differ significantly from those in new construction. The existing stock includes a variety of building types and materials. While new construction assumes certain qualities in materials, older buildings must be evaluated on a case-by-case basis.

Harvard's Daniel Schodek, an engineer, and Urs Gauchat, an architect, have developed a computer-based technique for the rapid analysis of the older-building inventory in a metropolitan area. They can identify the area's relative earthquake hazard as a function of seismic risk, soil conditions, construction type, and building age and occupancy.

Three California small business firms—Agbabian Associates, S. B. Barnes, and John Kariotis of Los Angeles—have formed



Quake test. Structural engineers at ABK-A Joint Venture in California hope that their tests of structural techniques and materials—such as this one done on an unreinforced concrete block wall subjected to simulated seismic motions—will lead to appropriate design and building code changes. We may then be able to minimize the loss of life and structural damage caused by earthquakes.

a joint venture to do research on the structural properties of unreinforced masonry and the typical construction of Southern California's older buildings. This work has resulted in recommendations for standards on masonry construction and the upgrading of existing masonry. These research results were also the scientific basis for a hazardous building ordinance enacted by the city of Los Angeles.

Research on techniques for seismic upgrading, repair, and retrofit is in progress in many labs across the country. Lawrence Kahn of the Georgia Institute of Technology is evaluating the structural contribution of externally applied shotcrete on unreinforced masonry walls. This technique is widely used and has been assumed effective; however, laboratory tests are calling that assumption into doubt.

Arthur Atkisson of the University of Wisconsin, Green Bay and William Petak of the University of Southern California are doing a study of the technical basis and operational success of regulatory efforts to reduce older-building hazards. The research has revealed complex legal, social, and economic constraints on building demolition; this discovery will affect the feasibility of various engineering solutions to the problem.

A project at the University of California, Berkeley has produced a way to give technical advice to homeowners. Materials developed by a team of architects and engineers enable homeowners to do a primary evaluation of their own homes and take relatively simple, inexpensive measures to make their housing more resistant to seismic damage.

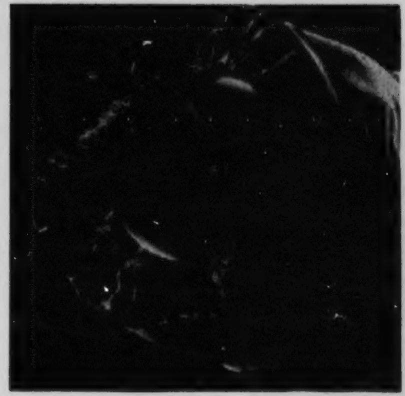
Research on the problem of existing buildings has been the subject of regional workshops in Boston, Seattle, San Francisco, and Los Angeles. Seismic hazard in older buildings has also been discussed in bilateral workshops in Japan, Italy, and the People's Republic of China.

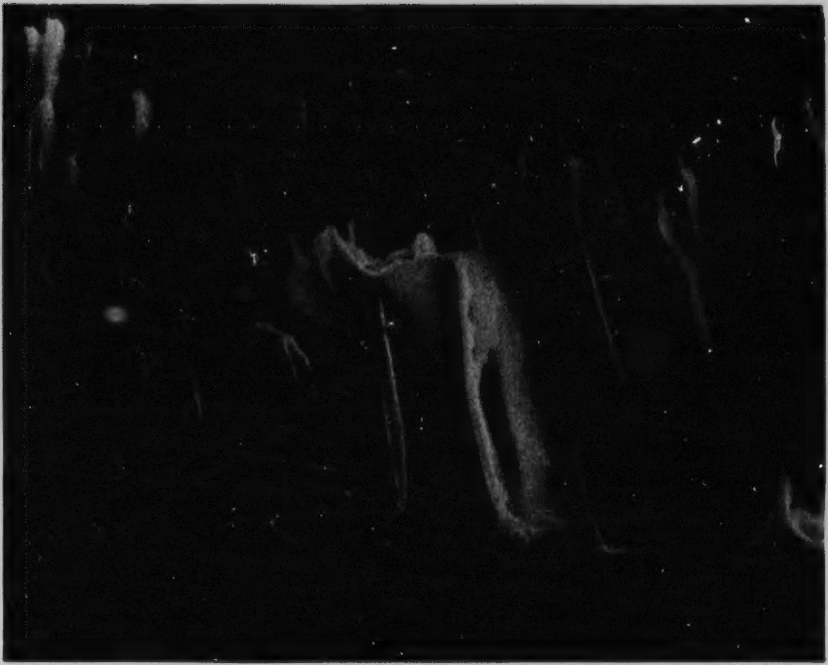
A New Method to Remove Viruses from Contaminated Water

During his study of a new method of solute concentration to remove contaminants from water, Georges Belfort of the Rensselaer Polytechnic Institute came up with a way to remove viruses from contaminated water—by ultrafiltration through hollow fibers made from polysulphone. Each fiber consists of a dense layer on its inside, supported by an outer porous substructure.

Using convective and electrical polarizing fields, Belfort found that retardation, and hence concentration, were much lower than expected for certain solutes. For instance polio virus recovery, using convective polarization in modules containing many hollow fibers, was excellent. Virus particles adhered to the interior surface of the fibers through which the contaminated water flowed, while water passed along those fibers.

In addition to this use, the technique has other potential applications, such as in processes to separate metals from plating baths, gene-splicing procedures, and biomedical processes that require the separation of extremely small particles from aqueous suspension.





Polysulphone fiber. This material has been used to filter viruses and other solutes from water. (Photo above shows a single hollow fiber, magnified 100 times; other photo is a cross-section of a single fiber, magnified 1,000 times.) Environmental engineer Georges Belfort at Rensselaer Polytechnic Institute developed this novel method of solute concentration. It can be used in a variety of scientific activities, such as gene splicing.

Mechanical Engineering and Applied Mechanics

NSF's programs in mechanical engineering and applied mechanics range from basic research into the foundations of mechanics, the mechanical strength of solids, and the fundamentals of heat transfer and fluid mechanics to the study of robotics, the theory of automated manufacturing, and the development of nondestructive evaluation techniques.

Experiments in fluid mechanics that combine laser and hot-wire anemometers have shown that current standards for measuring fully developed axisymmetric turbulent jets may be seriously in error. Since measurements of velocity, temperature, and turbulence intensity made by many investigators have been in agreement, these measurements were assumed to be correct, and turbulence modelers have used them extensively. Apparently, however, errors are caused by the very low velocities at the outer edge of the jet and the relatively high turbulent fluctuations within the jet proper. As a result of recent findings, all previous results on turbulent jets should be reexamined; some earlier failures in prediction then might be explained.

In solid mechanics, the results of linear elastic fracture mechanics are being incorporated into structural design codes, leading to safer and more efficient structures. Researchers report progress in developing theories for the nonlinear inelastic fracture analysis of ductile materials. These theories also are needed for advances in structural efficiency and safety.

In heat transfer, new experimental and theoretical results are giving valuable insight into the general characteristics of convection phenomena. Research on density and species differences, and their interaction when the thermal and diffusive processes occur simultaneously, is now being used to study convection in multiphase processes.

Mechanical systems engineers studying machine dynamics and dynamic systems and control continue to develop ways to help industry design high-speed mechanical and electromechanical systems. One example is application of the center manifold theorem to certain partial and ordinary differential equations that arise in structural mechanics. This application permits a significant reduction in the dimension of these equation sets.

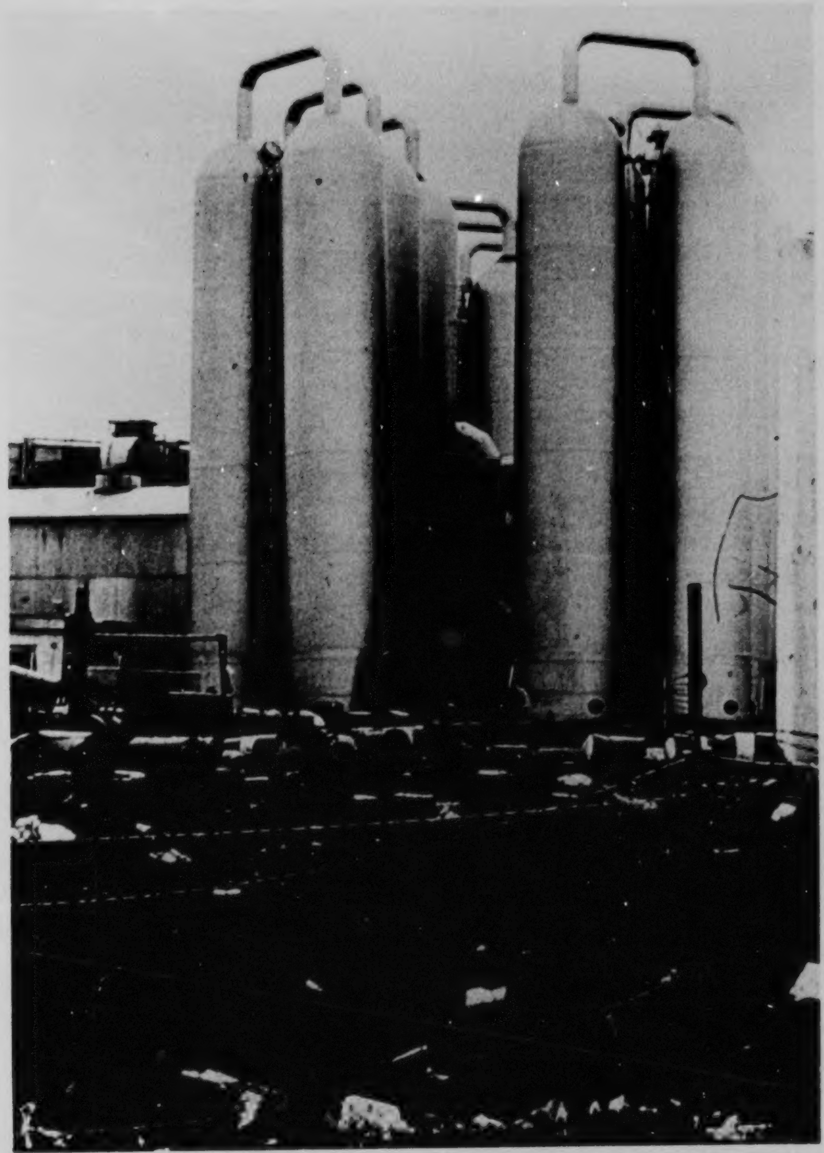
There are also advances in design sensitivity analysis aided by computers and in optimization for dynamic mechanical systems. In tribology, work continues on experimental testing to set design criteria for compliant surface bearings.

In production research, sensors for adaptive machining have come far enough that tool speeds and feeds can be adjusted to take into account tool, machine, and workpiece conditions so as to maximize production. In addition, research on industrial robots with vision capability has reached a point where its application to complex assembly operations is expected.

Constraint Variations Along Complex Crack Fronts

Most inservice fractures in high-strength structural materials are preceded by a period of subcritical crack growth. During this period tiny flaws located in thick, reinforced regions of high stress enlarge into cracks that often exhibit curved fronts and nonplanar surfaces. When a crack reaches a certain critical size, it becomes unstable, resulting in a sudden and often catastrophic failure of the component or structure. Such conditions occur in structures as diverse as gun tubes, bridges, nuclear-pressure vessels, offshore oil rigs, aircraft engine mounts, and gas and oil pipelines.

Researchers at Virginia Polytechnic Institute have noted a curious and unexpected phenomenon: In general, the crack growth they observed was not self-similar. That is, the shape of the flaw boundary changed as the flaw grew. The regions of greatest growth were those of the lowest stress intensity factor, which is a measure of the stress at the tip of a sharp crack. (Usually the higher that factor is, the faster the crack will grow.) According to the photoelastic models used in this investigation, which has been under way since 1973, the only possible explanation for this anomalous behavior was a constraint variation in the material. That is to say, a material particle was constrained by its surrounding material, just as an automobile is constrained by other vehicles in stop-and-go traffic.



Catastrophic failure. Debris on the ground in this photo is all that was left of a pressure vessel that developed small cracks and eventually failed. The vessel had contained compressed air for wind tunnel research; the large standing structures are similar vessels that did not fail. Engineers studying crack formation in high-strength structural materials hope to translate their research results into future cost and materials savings.

Using an optical displacement-measuring technique developed by Daniel Post at VPI, C. William Smith has obtained measurements to assess the degree of transverse constraint along the flaw border. With further refinements, this method will be used to correlate constraint variation with the distribution of the stress intensity factor in complex three-dimensional, cracked-body problems.

One implication of this research is that high-strength structural materials are much more resistant to crack growth in complex situations than is usually assumed. This increase in resistance, when quantified, can be translated into considerable savings in cost and materials for high-technology structures.

This work complements the research described in chapter 1 (on microscopic effects in defect propagation).

Generalized Wake-Integral Method For Three-D Bodies

In 1925, Albrecht Betz presented a theory on the drag forces acting on lifting bodies in free flight. He resolved this phenomenon into a profile drag component and an induced drag component. The first was expressed as a wake integral—i.e., a measure of the total horizontal disturbance left behind in the wake of a body as it translates forward.

The second component, induced drag, is the result of lift. Experimental determination of induced drag presents serious difficulties, since small quantities (transverse velocities) must be measured over large regions (two transverse planes, ahead and behind the body). These difficulties mean added cost and potential inaccuracy.

The current need for fuel-efficient vehicles focuses attention on better ways to predict drag and identify drag-producing mechanisms. James C. Wu of the Georgia Institute of Technology and James E. Hackett of Lockheed-Georgia have begun a joint university-industry cooperative research project to extend Betz's theory to general three-dimensional bodies.

Earlier, Wu and Hackett had modified the treatment of induced-drag computation and had accurately determined the drag of an unstalled wing (one with an unseparated flow of air across it). However, the wake-integral approach had not been attempted for more complex air flows involving separations, such as those encountered in the aerodynamics of cars with trailers.

An extensive experimental program obtained comprehensive survey data to test the general wake-integrated method. A semiwing model and a car model were tested, using the cross-section, low-speed wind tunnel at Lockheed. These two models represent, respectively, the limiting cases of flow from an aerodynamically shaped body with smooth, attached air flows to a bluff body with massive separations. The wing model was also tested at various angles of incidence to get data for mild air-flow separation.

The experiments have verified the theoretical prediction that total drag can be accurately determined through wake surveys close to an unstalled (unseparated air flow) wing. The same conclusions apparently apply to complex flows involving stalled wings and bluff bodies, such as cars. The accuracy of the data for complex air flows must be examined in more detail, due to limitations in the measuring probes.

Interdisciplinary Research

NSF established an Office of Interdisciplinary Research (OIR) in November 1981. Its aim is to coordinate research efforts involving more than one discipline. This move will encourage the dynamic new developments that often arise when two or more disciplines are fused in a new way to solve a problem.

Through OIR, NSF encourages interdisciplinary collaboration, aids joint funding, and stimulates joint program-development activities. The latter include workshops to identify research needs or priorities and cross-program statements for use in planning and budgeting. Recently, the interdisciplinary effort at NSF has been bringing together programs that focus on biotechnology and robotics/automated manufacturing.

NSF also supports workshops and conferences to highlight emerging and complex areas of interdisciplinary research, determine research needs, and encourage cross-discipline communication.

As part of this effort, NSF supports investigators who report on present knowledge and identify long-term research needs. An example is a paper on computer-aided design/computer-aided manufacturing (CAD/CAM), written by Richard F. Riesenfeld of the University of Utah. CAD/CAM is a growing field that uses interactive computer graphic techniques to aid product design and to couple the design and manufacturing processes. Riesenfeld's paper points strongly to the need for interdisciplinary research to integrate the fairly sophisticated CAD systems with less developed CAM systems.

Integration is the key to payoffs in higher productivity and better products. One major potential value of CAD/CAM is the ability to design products through computer modeling and simulation of the manufacturing process. Production planners would use this information to decide on optimal manufacturing strategies to make the best use of materials and resources.

Among the efforts needed to advance the CAD/CAM state-of-the-art are interdisciplinary research in computer graphics, interactive computing, systems design, and interpretive languages. Because of the breadth and complexities of the field, such research might best be done by teams of researchers. One immediate need is a higher-level, abstract model that is complex and sophisticated enough to drive all the necessary processes. A second major problem is building the interdisciplinary manpower pool needed to advance this emerging field.

Biological, Behavioral, and Social Sciences

3

Diversity is a striking feature of the research supported by NSF in these areas. Subjects range from molecules to tropical rain forests, from phonemes to the national electorate. Between these extremes, items of scientific interest can include snails, family incomes, artificial language, leaf resins, lake systems, and brain hemispheres—indeed almost any living creature or elements or collections thereof.

Despite this apparently bewildering diversity, there is unity. The scientists who study neurons are linked to those who study social groups through their focus on living matter or its artifacts. Biology is the largest part of this NSF directorate, but it also represents such fields as anthropology, economics, psychology, linguistics, sociology, political science, human geography, and the history and philosophy of science. The interests represented by these relatively discrete approaches to the study of life forms have interacted, branched, and converged to produce hybrid disciplines. Among them are psychobiology, law and social sciences, biophysics and biochemistry, and an emerging area called information science.

A new program added to the Division of Social and Economic Sciences during fiscal year 1982 continues the trend toward integration. The Decision and Management Program is a collaborative effort by four NSF directorates: Mathematical and Physical Sciences; Engineering; Scientific, Technological, and International Affairs; and Biological, Behavioral, and Social Sciences. Other integrative activities during the year included the full incorporation of applied research into the biological, behavioral, and social science programs of the Foundation.

Another development of note during 1982 was the beginning of a modest effort to support equipment needs at marine biological stations. To reverse a decline in the physical plants of these vital facilities, several divisions in the Foundation launched a special annual competition. Response to the solicitation, both in the number and quality of proposals, indicated a significant need; it will be met by a continued and expanded program.

NSF supports many of the more exciting areas of current scientific research, including the explosive developments in biotechnology. The Foundation aids the basic research underpinning the burgeoning commercial developments there.

The neurosciences verge on a revolution closely rivaling that in biotechnology and indeed resulting in part from shared techniques. Decades of basic research on the brain and the nervous and endocrine systems have begun to unravel mysteries as ancient as consciousness. Clues to understanding perception, cognition, emotion, and a host of other neural phenomena cascade from neurobiology laboratories at a breathtaking rate. Anxiety, depression, and Parkinson's disease are viewed with new insight. Improving intelligence chemically may no longer be confined to science fiction. These and other developments will keep the neurosciences in the forefront of scientific interest and importance for the foreseeable future.

Basic research in the plant sciences is a third area of major emphasis. Similar to but distinct from the research in bacterial genetics, plant science research also promises enormous commercial payoffs in forest and field and exciting discoveries in the laboratory and greenhouse. As reported in the NSF magazine *Mosaic*, "Scientists [are] determined to produce plants that have better nutritional qualities, resist stress, produce protein and carbohydrates more efficiently, provide their own fertilizer from the air and soil, and even photosynthesize more efficiently to feed and fuel humankind's next century."

The estimates are that plant genetics is about 20 years behind bacterial and animal genetics. But opportunities arising from

Table 3
Biological, Behavioral, and Social Sciences
Fiscal Year 1981 and 1982

(Dollars in Millions)

	Fiscal Year 1981		Fiscal Year 1982	
	Number of Awards	Amount	Number of Awards	Amount
Physiology, Cellular and Molecular Biology	1,484	$ 78.23	1,474	$ 80.11
Environmental Biology	753	41.05	711	41.99
Behavioral and Neural Sciences	744	35.26	697	31.74
Social and Economic Sciences	489	25.10	432	17.56
Information Science and Technology	59	5.94	72	5.20
Total	**3,529**	**$185.58**	**3,386**	**$176.60**

SOURCE: Fiscal Years 1983 and 1984 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

the transfer of techniques and knowledge to the botanical realm are developing at a rapid pace.

The explosive development of these and other areas of research, along with the relatively modest resources available, has produced a climate requiring continuing adjustment by NSF. Priorities must be juggled between areas of research, between new investigations and established ones, between equipment and salaries, mainstream and less traditional research, and long commitments or new starts. Some results of this weighing process are reported here.

Physiology, Cellular and Molecular Biology

Progress in biology research at the cellular and subcellular level has burgeoned in the past several years, and there is every indication that the explosion of knowledge will continue. Among the major contributing factors to this phenomenon: the development and adaptation of advanced instrumentation and the use of new biological procedures.

At the instrument level, computers enable much more information to be gathered in less time. They also allow the manipulation of that information in order to produce integrated pictures of cell structures. At the biological level, the considerable effort put into developing hybridomas—cellular hybrids between mature cells of the immune system and tumor cells—has led to production of substantial quantities of extremely specific antibodies. These monoclonal antibodies, labeled with fluorescent compounds, become probes to identify molecules embedded in cell components. When the fluorescent probes are observed and analyzed with computer-aided microscopes, scientists can get new information about cell structure and the mechanics of cell division and development.

Advances are also being made at the biochemical level. Almost a decade ago, NSF-supported scientists did experiments that showed it is possible to remove pieces of the chromosomes of higher organisms and incorporate them into the genetic material of bacteria. Further, we can determine the arrangement of nucleotide bases that together make up a gene.

Analysis of eucaryotic chromosome structure offers clues as to how the genetic information in the nucleus of each plant or animal cell is expressed—and how that expression is regulated. These clues come from research at the molecular level, where the properties of DNA, proteins, and their interaction are being studied. Other information comes from recently developed techniques to introduce purified genes into cultured cells by linking them to replicating parts of viruses. This powerful tool to examine the DNA sequences required for normal gene expression and regulation has been limited by the availability of cell lines that can be propagated *in vitro*.

For many genes, we anticipate that expression or regulation may be difficult to study *in vitro* because the required cell type may not be suitable for analysis in culture. Or developmental programming in the animal may be essential. New techniques for injecting DNA into fertilized mammalian eggs allow us to study the expression of defined DNA sequences in all of the different types of body cells. This will provide a valuable system for studying tissue-specific regulation of gene expression.

More than ever before, basic researchers in molecular biology are directing their efforts to challenges that are relevant to the problems of society. Moreover, it is not just the highly publicized experiments in "genetic engineering" that will give useful results. For example, there are now practical applications of past research on the fundamental physiology and metabolism of insects.

DNA Structure and Genetic Expression

Thirty years ago James Watson and Francis Crick discovered that DNA, the basic genetic material, existed in the form of a double-stranded molecule. The two strands of this molecule are wrapped around each other and each is in the form of a right-handed helix, resembling a clockwise corkscrew. It has been generally assumed that all DNA exists in this form under the conditions found inside living cells.

The two-stranded, complementary nature of DNA immediately suggested a mechanism by which DNA could be replicated during cell division. The general outline of this mechanism has been confirmed. An important question still to be answered is this: How do cells control which regions of their DNA are expressed in different tissues?

Some recent results in the laboratories of Alexander Rich at MIT and David Stollar at Tufts University have shed new light on this question. Rich and his colleagues have discovered that DNA can also exist in the form of a left-handed or counterclockwise double helix. Because of the way the sugar-phosphate backbone zigzags along the molecule, this form of DNA has been designated Z-DNA.

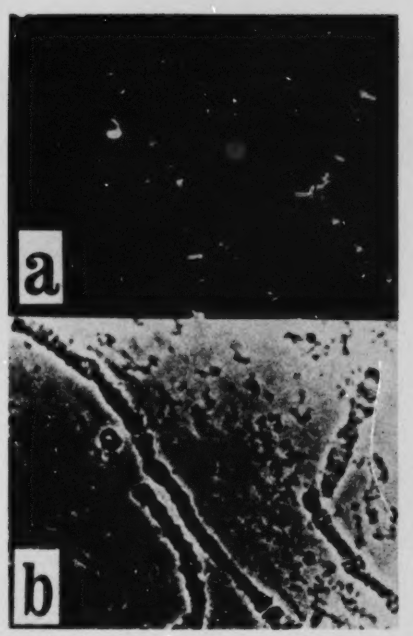
At first the Z-form of DNA was thought to exist only in synthetic molecules assembled in the laboratory. Stollar and Rich injected synthetic Z-DNA into rabbits and mice to produce DNA-specific antibodies. These interacted with Z-DNA but not with normal DNA. The antibodies therefore provided a specific probe to look for Z-DNA molecules or regions of DNA that exist in the Z-form.

When intact chromosomes obtained from *Drosophila* fruit flies were treated with fluorescent derivatives of these antibodies, the antibodies reacted with the chromosomes in a distinct and reproducible way. This indicated that regions of natural DNA also exist in the Z-form.

What is the significance of the regions of Z-DNA in natural DNA? We know that Z-DNA and the form of DNA observed by Watson and Crick are interconvertible under a variety of conditions. Stollar, Rich, and their colleagues have suggested that the Z-conformation may play a regulatory role in genetic expression by changing the local environment in or near particular genes, thereby altering or eliminating expression of those genes.

Another observation strengthens this suggestion. When DNA is altered by the addition of methyl groups, the Z-conformation is stabilized. Because methylation of DNA has been shown before to inhibit gene expression, it is tempting to suggest that the methylation effect is due to the conversion of DNA to the Z-form.

These results offer a new approach to the study of gene expression. Scientists may be able to show that when the genetic information for particular genes exists in the



Z-DNA in chromosomes. The light areas in frame a result from fluorescing the antibodies of a Z-DNA molecule, which was bound to specific regions in *Drosophila* chromosomes. Frame b shows the same chromosomes, using conventional light microscopy. Work with the Z-form of DNA—a left-handed or counterclockwise double helix—is helping scientists unravel the mysteries of gene expression.

Z-conformation, the expression of those genes is specifically suppressed. If so, they will gain an important insight into one mechanism to control gene expression in plant and animal cells.

Genetically Altered Mice

The initial impetus for developing the techniques now known as recombinant DNA technology came from the desire to understand how the genetic material (genome) of an organism is arranged—and how different parts of the total genome are called into action at different times during development from the fertilized egg to the mature organism. Despite the various important applications of this technology toward more immediately practical goals in health and agriculture, the fundamental scientific questions that began the DNA revolution are still very much in the forefront of basic biological research.

A significant advance in studying the control of gene expression comes from the work of Ralph Brinster, Richard Palmiter, and their colleagues from the Universities of Pennsylvania and Washington. They have succeeded in not only introducing a foreign gene into mouse embryos but also triggering the new gene to be expressed in the resulting adults.

The gene they introduced was that for the enzyme thymidine kinase, isolated from a herpes simplex virus. To this gene they attached the promoter or regulating DNA sequence from the metallothionein I gene of the mouse. In a normal mouse, this promoter is responsive to heavy metals, causing the expression of the metallothionein gene. In the fusion gene, it was hoped that the promoter would respond to the presence of heavy metals by activating the herpes simplex gene.

Brinster and Palmiter injected the fused genes into the nuclei of fertilized mouse eggs and then transplanted the cells into foster mothers to complete their development. They discovered that about 20 percent of the injected eggs developed into animals that contain the fusion gene, and more than half of these express the foreign gene.

Regulation of the expression for the thymidine kinase can be controlled as predicted by heavy metals such as cadmium and zinc. Expression was found only in tissues such as the liver, where the metallothionein gene is normally induced by exposure to the metals. The amount of thymidine kinase produced by these mice did not seem to be correlated in any way with the number of copies of the fusion gene, an important and somewhat surprising finding.

Another key discovery: The foreign gene can be inherited by offspring of the original injected embryos. When 54 offspring of a single injected mouse were examined, 34 were found to carry the gene. This suggests that the fusion gene was incorporated into one of the mouse's chromosomes and then passed, as predicted by Mendelian genetics, to roughly half of its offspring.

These studies are expected to lead to rapid advances in our understanding of how genetic information is selectively activated in different cells and at different times of development.

Mice expressing new genes. Scientists were able not only to introduce a foreign gene into mouse embryos but to trigger the expression of that gene after the embryos matured. This kind of work is adding much to our understanding of how genetic information is relayed.

Applications of Insect Biochemistry

Throughout the United States, with the exception of Alaska and a few northern continental states, termites inflict millions of dollars in damage each year to wooden houses, bridges, and other structures. Many years ago, bait blocks impregnated with a suitable termiticide became a promising alternative to flooding soil with chlordane to protect wooden buildings against termites—an environmentally damaging practice. However, the removal from the market of the delayed-action pesticide Mirex has crippled the efficacy of bait blocks.

Glenn Prestwich at the State University of New York at Stony Brook has devised a new strategy to develop a useful delayed-action termiticide. He has researched the biochemistry of fluoroacetate, a poisonous substance that occurs in plants such as *Acacia*. Fluoroacetate often kills wild and domestic animals who eat those plants.

The toxicity of fluoroacetate is due to the fact that in biological systems it is converted to alpha-fluorocitrate, a potent and irreversible inhibitor of citrate transport. Organisms are then unable to oxidize carbohydrates, which supply energy for their metabolic functions, and they die.

What Prestwich proposed to do is design a precursor which, after ingestion by the termite, would be converted *in situ* to fluoroacetate. It is known that omega-fatty acids with an even number of carbons—e.g., C_{12}, C_{14}, C_{16}, and C_{18}—are degraded to fluoroacetate. But fatty acids by themselves are unattractive to termites and are quite rapidly oxidized.

The next step was to increase the attractiveness of the omega-fatty acids and the time it takes to oxidize them to the poison itself. Prestwich prepared and tested a series of omega-fluoroalkyl and omega-fluoroacyl esters triglycerides and other derivatives against the eastern subterranean termite, *Reticulitermes flavipes.* He evaluated the compounds for delay time and toxicity in the laboratory, then tested the more promising candidates under simulated field conditions.

One compound, 16-fluoro-9-*E*-hexadecene-1-01, seems to have the most desirable complement of properties. Termites are killed by 20 to 200 nanograms per individual, with delay times of 24 to 72 hours and complete kill in 48 to 150 hours over the tenfold dosage range. Food sharing by termites within a colony spreads the poison evenly before the onset of toxicity. A mature colony, with 60,000 members, could be eliminated with 1 to 10 milligrams of the fluorolipid. As a followup to the NSF-supported basic research, this compound is now being field tested by the U.S. Department of Agriculture in Gulfport, Mississippi.

Roger A. Morse and Christopher Wilkinson of Cornell University are working on another aspect of insect biochemistry. All organisms have a multipurpose enzyme system—the microsomal mixed-function oxidases—for converting potentially toxic, fat-soluble, foreign compounds into water-soluble, excretable products. These scientists are testing the idea of inducing these detoxifying enzymes to protect commercially important insects, such as bees, from insecticides.

Scientists have found that some insects can be induced to manufacture mixed-function oxidases at a rapid rate if they are fed nontoxic oils. With large quantities of these enzymes in the gut, an insect may be able to break down an insecticide that might otherwise be lethal. This finding could explain why some insecticides are less toxic than others: Oils are included in some formulations to make the insecticide stick to the plants, and the oils may stimulate insect detoxification systems.

Most research along these lines has been done with pest insects and has sought to circumvent their ability to detoxify poisons. By contrast, Morse and Wilkinson are working with beneficial insects, honeybees, which are often accidentally poisoned by the insecticides sprayed into their environment. In preliminary tests they have found that a particular nontoxic oil fed to the bees reduced the toxicity of one insecticide by about 20 percent. They continue to test a wide range of enzyme-inducing substances that may ultimately enable us to protect useful insects from pesticides.

Shinya Inoue. At the Marine Biological Laboratory in Woods Hole, Massachusetts, Inoue is developing improved video-intensification systems and computer-based image reconstruction. These will add to our knowledge about cell structures and developmental processes.

Computer Applications to Cell Biology

The histochemistry of the 1940s and 1950s was responsible for many of the observations and findings that are the foundation of modern cell and molecular biology. Video-intensification systems, fluorescent probes, and computer-based image reconstruction have given cell biologists tools to unravel previously unapproachable problems. Their use has already forced cell biologists to reconsider some of their long-accepted tenets. Studies by Shinya Inoue of the Marine Biological Laboratory at Woods Hole, Massachusetts and John Sedat at the University of California, San Francisco, are two examples of the way this improved technology has meant new approaches to cell biology.

Inoue injected the fluorescent dye lucifer yellow into the four smallest cells (micromeres) of a 16-cell, sea-urchin embryo. He found that this does not interfere with later cell division or development of the embryo. As the cells divide, the fluorescent label is distributed equally between the daughter cells, and with further divisions it is progressively diluted.

By taping from a video camera attached to his light microscope and removing background noise with sophisticated computer programs, Inoue is able to follow the migratory behavior and destiny of the cells that descend from the earliest stages of embryo development. For example, the progeny of the micromeres form a ring of cells around the body cavity of the embryo, and Inoue has found that every fourth cell in this ring is labeled by the fluorescent marker.

This poses the intriguing problem that although these micromeres may be indistinguishable in their morphology and function, they each have a programming that also determines their spatial positioning among the daughter cells.

In San Francisco John Sedat also is using video-intensification systems—in his case coupled with what he terms "optical sectioning"—to determine the three-dimensional organization of cell nuclei. He has built a collection of monoclonal antibodies to specific proteins found in the nuclei of the insect *Drosophila*.

Specific antibodies are fluorescently labeled and added to permeabilized cells, which are then placed in a narrow capillary tube. The tube is laid in the focal plane of a light microscope and rotated around its long axis. For each angle at which the cell is viewed, a different pattern of fluorescence is seen and recorded on a video screen. The recorded information is then fed into a computer that reconstructs a three-dimensional picture from the fluorescent patterns.

With conventional light microscopy, the membrane surrounding the nucleus seems to disappear during an early stage of cell division. Later, new nuclear membranes are observed around the two sets of separated chromosomes, each set destined for one of the daughter cells.

To study the principles involved in this process, Sedat has used the fluorescent derivative of one antibody that is specific for a protein found only in the nuclear membrane. It uniformly stains the entire nuclear membrane of cells that are between divisions. By labeling nuclei at different stages of cell division, the fate of the nuclear membrane can be observed.

Contrary to what has been seen before, the membrane does not completely disintegrate during division but develops large holes and loose strands extending into the cytoplasm of the cell. At a later stage the staining begins to concentrate around the newly forming nuclei; it finally creates around them a distribution of fluorescence that is identical to that of the original nucleus.

The progress of any scientific discipline depends on the methods and instrumentation available for gathering new information. Such information then provides clues on how to approach the specific problem at the next level of complexity. The two studies cited above show how sophisticated morphological observations can give clues for studies at the biochemical or molecular level. Inoue's observations now make it possible not only to follow specific cell lineages but also to determine subtle macromolecular differences between cells at early stages of development. Sedat's study provides a probe and an *in vitro* experimental system for investigating complex membrane assemblies.

Environmental Biology

This Foundation division supports research on biotic systems and biotic diversity. A biotic system involves an interactive relationship between an organism and its environment or an assemblage of organisms and their environment, which may include other organisms of the same or different kinds. Biotic diversity manifests itself both as subtle differences between individuals of one sort and the staggering array of distinct organisms.

The thread that binds these two seemingly diverse concepts together is spun by geologic time and mutual dependence. Cited below are a few examples of currently supported research that illustrates the integration of these two concepts.

In general, the organisms that constitute an effective breeding population share a set of characteristics that distinguishes them from other breeding groups of the same type of organism. Time and genetic interdependencies within each breeding group allow it to evolve its special attributes. But some organisms seem not to follow the usual "rules" and—as in the case of the *Cerion* snail described below—have puzzled taxonomists for generations.

The special peculiarities of a population normally do not become established randomly; they reflect an adaptation to some environmental pressure on the evolving organism. Many of the chemicals or natural products elaborated by plants seem to offer protection against the pressure of excessive attack by herbivores and disease agents. The resins of certain tropical trees play this role in one study detailed below.

Some of these natural plant products—such as latex, quinine, digitalis, peppermint, and citronella—have special uses by human beings. More recently the predator-deterrent qualities of some plant products have been applied to the control of crop pests.

While this latter technique sounds practical and promising, other studies of biotic systems remind us, as manipulators of our environment, to exercise caution. Those systems are enormously complex, sometimes resilient and forgiving of insult, but just as often delicately balanced and easily upset. The decades-long study of Lake

Tahoe described below shows how man's various activities—sometimes gradually, sometimes precipitously and catastrophically—can degrade a biotic system.

The Lake Tahoe example also illustrates another point: To understand the structure and functioning of landscape-scale biotic systems adequately, we need long-term intensive research in a variety of carefully chosen, representative habitat types. To that end, the Foundation is supporting a series of integrated, long-term environmental studies; they are examining in detail the dynamics of a variety of habitats—coniferous forest, grassland, fresh-water lakes, tidal estuary, and desert. A glimpse of the approach used comes from the study of energy and materials moving through a soil subsystem, as described later.

The Diversity of Cerion

Experts agree that the West Indian land snails of the genus *Cerion* are among the most difficult to classify. *Cerion* presents one of nature's most impressive displays of morphological variety, and 600 species have been described on the basis of shell form. The problem is that these species have evolved without significant genetic differentiation or the attainment of reproductive isolation. Either most *Cerion* species are invalid or there is something wrong with the biological-species concept itself, because current theory holds that species are genetically distinct and reproductively isolated.

Evolutionary biologists Stephen Jay Gould (Harvard University) and David S. Woodruff (University of California, San Diego) are collaborating on a study of these remarkable snails. Their work focuses not only on the resolution of *Cerion*'s taxonomic problems but also on learning what these organisms can tell us about the processes of adaptive radiation and speciation in general. The two scientists are using a combination of field work on the ecology and distribution of living and fossil snails and laboratory studies of genetics, anatomy, and shell morphology. They are thereby elucidating major patterns in the evolution of this group.

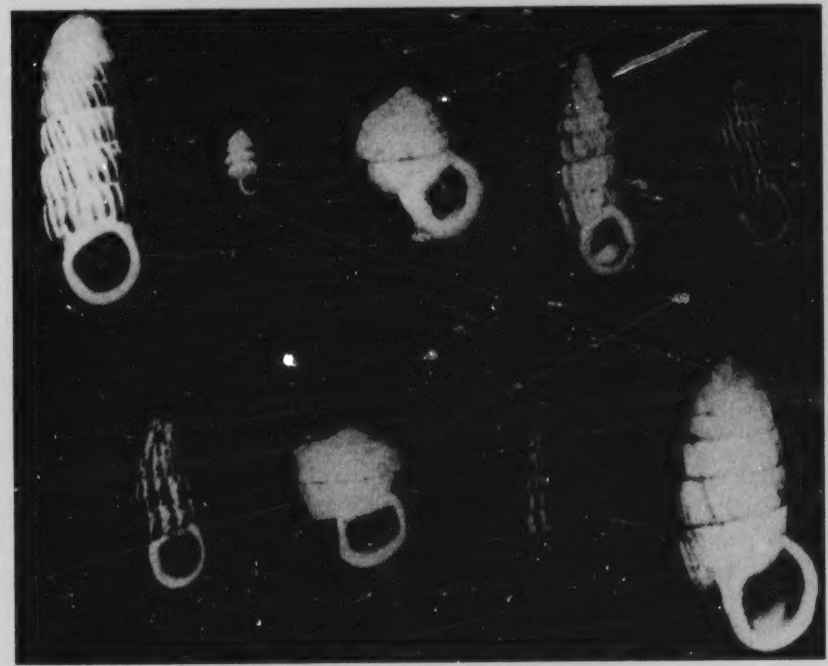
In the Bahamas, the team found more than 250 named species with crazy-quilt distribution patterns throughout the islands. Gould and Woodruff sampled snails from more than 1,000 localities, measured shells from each site, and characterized the genotype of the snails whose shells they had measured. In addition, they studied the anatomy and ecology of the animals at selected sites.

The scientists concluded that there are not 250 species of *Cerion* in the Bahamas but probably about 10. Five of these are widespread today and probably evolved in the Bahamas during the last 100,000 years. Several others have apparently been blown into the area from Cuba by hurricanes. These species exhibit very low levels of genetic and anatomical differentiation, but the morphology of each is highly and distinctively variable. Woodruff and his students have shown experimentally how some of this variation in shell morphology relates to the snails' adaptation to thermal stress and predation by land crabs.

This case is particularly interesting because morphology is a poor indicator of species status in this group. More generally, *Cerion* suggests that reproductive isolation may have been overemphasized in earlier species concepts developed by zoologists. It turns out that most *Cerion* species, even the most dissimilar, will hybridize where their ranges come together in nature.

Gould and Woodruff have found many narrow hybrid zones separating species in *Cerion*. Woodruff, who has been studying the evolutionary significance of such zones, has observed that snails of these areas exhibit genetic anomalies. Samples from the hybrid zones have rare or unique electromorphic alleles at frequencies 10 to 100 times higher than those away from the zones.

The causes of this new genetic variation are unknown and still under investigation at this writing. The spread of the alleles from the hybrid zone is being followed in nature by researchers who monitor the movements of hundreds of individually marked snails. This work will help scientists develop a more comprehensive picture of the zone's gene dynamics than has been possible before. The results are expected to clarify patterns of evolution.



Cerion diversity. Mature adult shells of this snail species (*Cerion*) differ dramatically in appearance. These nine species represent some of the diversity seen in Cuba and the Bahamas. The largest specimen here has a length of 45 mm; a snail with a shell 70 mm in length lived in Mayaguana Island in the Bahamas until a few thousand years ago. Despite the great variety in morphology, though, there are probably far fewer species of *Cerion* than we once thought, according to recent research. Long-term studies of such animals reveal the importance of gene flow in the speciation process. (Photo by David Woodruff)

Resin Production in Tropical Trees

Evolution and ecology. Biologist Jean Langenheim takes an evolutionary approach to ecology through the study of amber and plant development. Here she displays a chunk of resin, or amber, from an amazonian *Hymenaea* tree. The resin deters attack by insect predators; its chemical composition is so characteristic for each species—whether in Africa or in Central or South America—that comparisons help to reveal evolutionary pathways

The distribution in plants of complex molecules called terpenes is taxonomically significant. In the legume family (*Leguminosae*) complex mixtures of sesquiterpenes and diterpenes occur in the resinous excretions in bark, leaves, and fruits. The mixtures of the various compounds may be so characteristic and specific that they can serve as "fingerprints" to distinguish species and subspecies and to identify plants of hybrid origin.

Terpene diversity is particularly high in tropical rainforest plants. Presumably this reflects the evolution of terpene-producing capability in forest plants as deterrents or defenses against the attacks of herbivorous insects and possibly fungi.

Jean Langenheim, at the University of California, Santa Cruz, found that some Mexican ambers were derived from the resins of the algarrobo tree (*Hymenaea*). Using infrared spectrophotometry, Langenheim discovered that the resins in the leaves of the related legume genera *Hymenaea* and *Copaifera* are similar. The same 15 terpenoid compounds occurred in the leaves of all species investigated, but the proportions of the compounds varied between species.

Langenheim has tested different terpene contents for their deterrence power by offering the leaves to a herbivore, the beet armyworm. The resins reduce the palatability of the leaves, and the terpenes show varying deleterious effects on the armyworm larvae. Chemical defenses against herbivore attack are probably especially important in the seedlings of *Hymenaea*, which have few leaves and grow slowly during the first few years.

Langenheim has also compared terpene patterns in South American and African populations of *Hymenaea*. The similarity in the kinds of leaf resins is remarkable. For example, a common East African species *H. verrucosa* has a complement of leaf resins very similar to that of *H. courbaril*, common in the tropics of the New World. Similar transatlantic resemblances in leaf resin are also found in the related genus *Copaifera*.

This evidence strongly suggests a typical "Gondwana" pattern of distribution, resulting from the gradual separation of South America and Africa. Geological evidence indicates that these continents began to drift apart in late Cretaceous times, a finding substantiated by recent studies of early Tertiary (Oligocene) amber from the Dominican Republic. The terpenoids in that amber prove to be much more like those of the east African *H. verrucosa* than those of any other species now living in the New World.

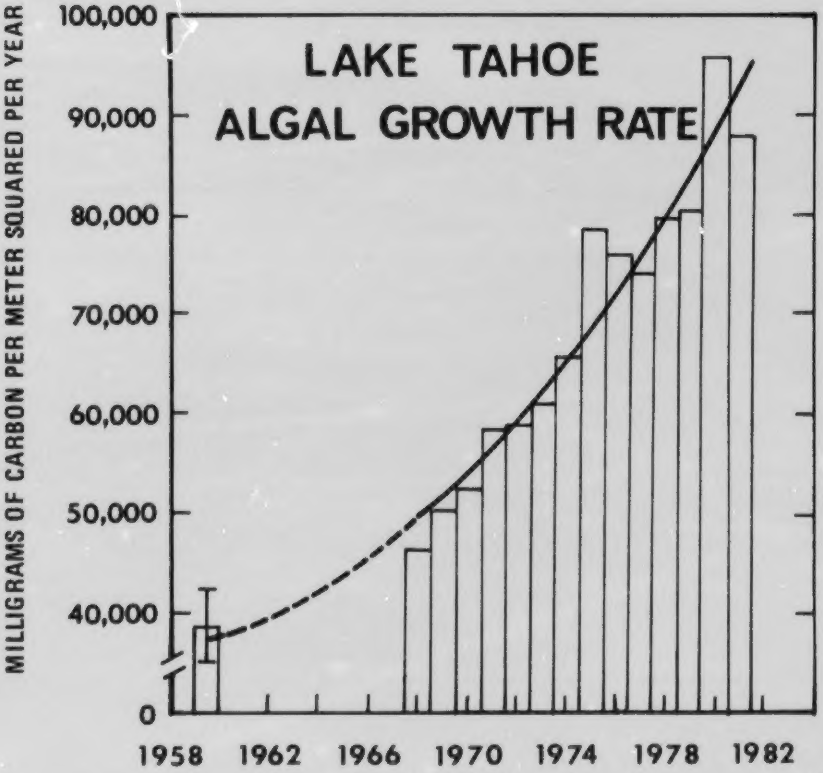
This work is a striking example of the insights possible through research at the junctures of taxonomy and ecology in tropical plants. It also illustrates how former world geography can be revealed through the study of modern natural plant products.

Structure of Aquatic Communities

For many years lake ecologists, or limnologists, have studied communities of planktonic plants (phytoplankton) and animals (zooplankton). The mechanisms that determine abundance and composition in planktonic communities have proven rather elusive; yet they are crucial to understanding the way lake systems function. Research has clarified many of the structural and regulatory uncertainties and is giving information that can be useful in lake and fisheries management. Work at Lake Tahoe on the California-Nevada border has been a prime contributor to these advances.

Lake Tahoe lies high in the Sierra Nevada mountains and is one of the world's most distinctive lakes. Its transparent, cobalt-blue water has survived about two million years, but evidence indicates that this pristine character is degrading rapidly. Long-term ecological research has documented changes in the lake and given invaluable insight into their underlying causes. The Tahoe Research Group, directed by Charles R. Goldman of the University of California, Davis, is the major vehicle for research on the lake; its work has contributed greatly to advances in planktonic ecology.

Since 1959, Goldman and his associates have systematically measured the abundance of phytoplankton, zooplankton, and, to a lesser extent, periphyton (algae attached to surfaces). In two decades of observation, the standing crop of planktonic algae has more than doubled. As a result Tahoe's famous clarity is suffering; water transparency has decreased more than 10 percent since 1970. The increasing growth of algae and the loss of clarity have been traced to urban development in



Disrupted ecology. The once-abundant consumers of algal phytoplankton in Lake Tahoe were destroyed by the predatory opossum shrimp (*Mysis*), introduced into the lake without proper study beforehand. As a result, the algae have grown more abundant and the water is less clear.

Lake Tahoe's drainage basin and the increase of nutrient inflows that urbanization generates.

The animal plankton of Lake Tahoe changed dramatically in 1971 and remains altered to this day. Two populations (*Daphnia and Bosmina*) disappeared totally from the lake's zooplankton. This loss is significant because these crustaceans, which feed by sweeping the tiny algae from the water, are a major source of food for fish, especially juveniles. The opossum shrimp *Mysis*, introduced into the lake in the early 1960s by the California and Nevada fish and game departments, was found to be the culprit.

The Tahoe Research Group studied the abundance, growth, spatial distribution, and age structure of the Tahoe *Mysis* population to gain insight into the shrimp's amazing success in the lake. Food-selection and feeding-rate studies found *Mysis* to be an omnivore and a voracious predator on small crustaceans, preferring the two species that had disappeared in 1971. Thus the opossum shrimp was clearly linked to the extermination of the *Daphnia* and *Bosmina* populations in Lake Tahoe. Besides eliminating these two crustaceans, *Mysis* is also the probable cause of the recent decline in the kokanee salmon population. It seems to have reduced the salmon's food supply.

The *Mysis* story is a classic example of how a seemingly unimportant organism can induce widespread changes in lake dynamics. The Tahoe research has given new insight into the role of predators in structuring an aquatic community and has also provided information useful in lake and fisheries management. Contributions of the Tahoe Research Group are outstanding examples of long-term ecological research.

Control of Nutrient Cycling by Soil Heterotrophs

Nutrient cycling and energy flow are integrative processes that link the physical, chemical, and biological aspects of ecosystems. These processes regulate ecosystem structure, function, and development within boundaries defined by climate and parent geological material.

Contrary to common belief, most of the fixed carbon and associated nutrients in ecosystems are distributed below ground as roots (living and dead), root exudates, and litter. Therefore, the major part of nutrient cycling and energy flow in an ecosystem occurs underground.

For example, research by D. C. Coleman of Colorado State University shows that 86 percent of biomass production and 95 percent of heterotrophic production and respiration take place in below-ground components of semi-arid grassland ecosystems.

Although climate and soil properties are important factors affecting below-ground nutrient dynamics and energy flow, biotic interactions among soil fauna and flora significantly affect the development and function of ecosystems. Soil organisms play major roles in processing organic material and in moderating associated nutrient mineralization; they do so by directly or indirectly influencing rates, transport, and transformation of compounds. Research at Colorado State, under the direction of Coleman and C. V. Cole of the U.S. Department of Agriculture, is elucidating the role of soil biota in complex below-ground processes.

A major effort by the Colorado group has been to assess the role of soil fauna in litter processing and nutrient mineralization. Results of their studies suggest that soil fauna play a large and direct role in the physical, chemical, and biological processes of nutrient dynamics. Or they indirectly moderate these processes by feeding on the microflora.

Medium-sized animals—mesofauna such as earthworms, ants, and termites—fragment and incorporate litter and detritus into deeper soil layers. By consumption and digestion they increase the nutrient content of the processed material. Earthworm casts are enriched with microflora; this increases decomposition rates. The microfauna, nematodes and protozoans, maintain a dynamic nutrient flux by grazing on primary decomposers (mostly bacteria and fungi), by increasing substrate usage and decomposition rates, and by adding to nutrient mineralization via metabolic waste products. Root grazers may stimulate primary decomposer activity by increasing the amounts of substrates available from cell leakage and dead roots.

In a series of microcosm experiments, Coleman and Cole found that introducing an amoeboid protozoan and bacterial-feeding nematode increased both decomposition and nitrogen and phosphorus mineralization. By grazing on microbes, nematodes boosted substrate use and microbe diversity. They also added to nitrogen mineralization by excreting microbially immobilized nitrogen. Because of short life cycles and nutrient-rich excretory products, these microfauna help maintain a dynamic nutrient pool. In returning nutrients rapidly to the soil, the microfauna help to sustain the high metabolic activity of the primary decomposers.

Although many key interactions can now be identified, these results suggest intriguing problems in separating plant structure and function from other environmental/biological components. The microflora and microfauna are intimately linked with the primary producers and soil constituents in a complex and dynamic series of biotic interactions. These are essential to maintain the productivity and nutrient dynamics of ecosystems.

These and similar findings have profound implications for current efforts to increase agricultural productivity. By disrupting soil-organism relationships, some common patterns of herbicide, pesticide, or fertilizer application may in fact be counterproductive.

Behavioral and Neural Sciences

Research supported by the Foundation in this area is unusually broad, including anthropology, linguistics, psychology, and neuroscience. A common goal of all these disciplines is to advance our understanding of behavior and the biological, environmental, and cultural factors that influence it. These four disciplines, although often quite different in subject matter, methodology, and general approach, also share common concerns.

The current research focus of them all is the topic of development. Anthropologists are examining both contemporary and older civilizations to understand how societies and cultures have developed and how they continue to adapt. Linguists and psychologists are accelerating our knowledge of how cognitive capacities develop, especially in very young children. Neuroscientists are making rapid progress in understanding how nerve cells grow great distances with marvelous accuracy, making precisely appropriate connections in a developing organism.

Analyzing development is perhaps most difficult at the cultural level. There the anthropologist interested in an earlier civilization must piece together an inferential jigsaw puzzle, with key pieces of data often missing. A question for archeologists is how social complexity develops and is maintained. When one takes a broad perspective and views humans over the several million years of their prehistory, this process—the development of large communities, of chiefdoms, and of states—moved very rapidly and independently in many parts of both the Old and New Worlds.

One way to understand these developments is to study trade relationships among ancient sites. Geologists, geochemists, and archeologists have located obsidian deposits in many areas of the world, with particular attention to Middle America. The influence of various Mexican states, their rise, the expansion of their power, and their decline have been traced by reconstructing changes in obsidian trade networks.

Much research has been done to understand cognitive skills in children as young as two or three. Work on the development of number concepts, by Rochel Gelman of the University of Pennsylvania, is already beginning to have practical use in a number of preschools in the Philadelphia area. Gelman has documented the capacity of young children to understand number concepts far in excess of what was expected. She has also carefully documented their limitations. Using this information, preschools have been able to design their curricula to make creative use of the childrens' capacities so that they reach their maximum learning threshold.

At the cellular and subcellular level, recent advances in neuroscience research have just begun to open new doors to understanding how the exquisitely complex human brain develops and functions.

The brief research descriptions that follow are but a few examples of exciting accomplishments in the behavioral and neural sciences, illustrating both the depth and breadth of contemporary work in these rapidly progressing areas.

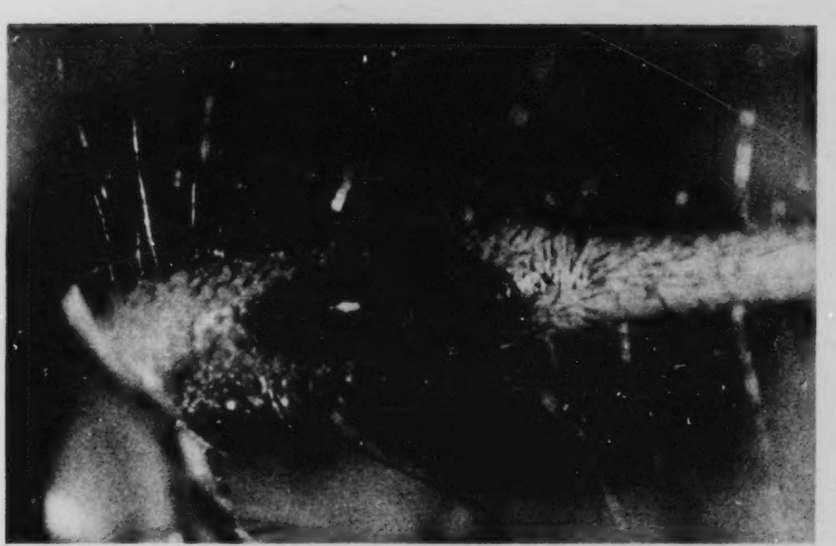
Developing Brain Maps

Most nervous systems focus on stimulation from the outside world by creating a "map in the brain." Such maps are assembled by the orderly growth of sensory neuron arrays—from peripheral sensory structures such as the eye to matching arrays of neurons on the appropriate part of the brain.

Rodney Murphey of the State University of New York at Albany has shown that development of the relatively simple nervous system of the cricket follows the same pattern. He used recently invented dye-injection techniques to show that each sensory neuron projects to a precise area of the brain and that this patterned projection is repeated in every individual of the species. Furthermore, each neuron grows a synaptic terminal in a specific region of the brain that is correlated with its position on the body surface, thereby producing a somatotopic map in the brain.

The process of neuronal growth required to assemble such a map is seen in an extreme form in insects, such as the cricket, where sensory neurons are born in the epidermis. Without ever having been to the brain, these neurons are able to grow axons to the brain and make orderly synaptic connections. Since insects have no immune system, it is easy to transplant the epidermis, containing the sensory neurons, to different places on the body in order to test their path-finding ability. Murphey has discovered that the brain region where a neuron makes synapses is fixed at the time of the neuron's last cell division, and during growth of its axon it makes a series of choices. These choices in the growth program are arranged hierarchically.

For example, if a leg sensory neuron is merely transplanted to a different location on the leg, it will find the leg area of the brain and grow to a place within that area appropriate to its original position on the leg. However, if it is transplanted to another leg, the neuron will grow to the brain part controlling the host leg—but will again



Neural mapping. A patch of epidermis from a black cricket, containing sensory receptor cells, has been transplanted onto a tan cricket. The purpose of this experiment was to study the growth of the transplanted cells into the central nervous system. Work like this gives us a new view of the way an insect's nervous system is constructed—and some ideas about more complex organisms as well.

arborize in a manner consistent with its original position on the donor leg.

Many experiments like this lead Murphey to conclude that the sensory neuron receives a set of instructions about how to arborize in the brain; these cues depend on the neuron's location on the body surface at the time of its birth. It seems never to forget this "positional information." Attempts to determine the nature of this information at a biochemical level can now be made.

These experiments give a new view of how an insect's nervous system is constructed. They also provide high-resolution studies of the assembly of a relatively simple nervous system; such studies are difficult or impossible to achieve in the more complex brains of vertebrates. Thus the brains of crickets and other invertebrates serve neurobiologists as model systems, the way bacteria and viruses serve molecular biologists. These models allow scientists to apply powerful techniques to complex problems and produce simple, elegant solutions.

Local Protein Synthesis

The axon of a nerve cell serves as the single line of communication between neurons, as well as between neurons and cells of peripheral organs such as muscles, sensory receptors, and glands. Therefore many axons represent extremely long, thin appendages of the neuron that may extend up to a yard in length. Continued maintenance of their structure is essential for normal nervous function.

The viability of the axon is maintained by a continuous supply of proteins from the cell body, the neuron's principal site of protein synthesis. Proteins include a wide range of functional macromolecules that make up the surface membrane of the axon and its terminals, in addition to many enzymes that control local metabolic activity in the axoplasm. A very efficient intracellular transport system ensures that most of these proteins reach their appropriate sites of function fairly rapidly—at rates of a couple of hundred millimeters per day. There is, however, a class of proteins making up the cytoskeleton of the axon that is transported at an extremely slow rate—about a millimeter per day.

Edward Koenig of the State University of New York at Buffalo has been interested in determining whether axons are capable of endogenous protein synthesis. If so, he would like to characterize and identify locally synthesized proteins, to find out what significance they may have for the growth of the axon. A major difficulty in such studies is that axons are always associated with metabolically active cells that form a sheath around them. In his research, Koenig has circumvented this difficulty by placing goldfish retinal fragments in culture. These cultured explants initiate axon regeneration and yield rich outgrowths of optic-nerve axons that are free of ensheathing cells.

Koenig has applied specialized microchemical techniques to study the microscopic axonal sample available after connections to the retinal explant are severed. His findings indicate that in these growing axons, there is a limited capacity to synthesize several proteins. Of considerable interest is the fact that two of the proteins Koenig has tentatively identified are components of the axon's cytoskeleton and probably are also part of the mechanism of intracellular transport. These proteins, which are potentially involved in vital growth functions, are normally supplied to the axon from the cell body at an extremely slow rate.

Other recent studies indicate that slowly transported proteins undergo a gradual degradation during transit. Koenig's findings imply that local protein synthesis may supplement some of the proteins supplied by slow transport; they may thereby compensate for the inexorable biological effects of aging and degradation. Impairment of local protein synthesis could explain axonal degeneration seen by physicians in so-called neurotoxic neuropathies and dying-back syndrome. Moreover, the potential for growth, regeneration after injury, or subtle "plastic" changes that result in rearrangement of neuronal connections may depend to some extent on local protein synthesis.

Visual Memory

We often take for granted how totally dependent human life is upon memory, from simply knowing one's location in space to speaking and comprehending. Those who have lost the capacity to remember are reduced to a vegetative existence. Yet, despite the unparalleled importance of memory, we know almost nothing about how the brain accommodates this function. A major reason for this ignorance is that no one has yet succeeded in identifying a set of brain cells that form the essential elements for any specific memory. A variety of experiments by Robert Doty of the University of Rochester addresses this issue, using visual memory in monkeys. Their visual system and memory capacity are remarkably similar to our own.

In these experiments, objects are arranged by means of a relatively simple and innocuous, but technically demanding, procedure. What the monkey sees with one eye passes directly only to the half of the brain on that side (rather than to both sides as in the normal situation). The only way the right half of the brain can then know what the left side has seen, and vice versa, is via two fiber bundles: the anterior commissure and the splenium of the corpus callosum. Either of these pathways alone is able to transfer this information, and for the types of visual input tested to date, for pure color, or for pictures of objects or scenery, the two pathways seem equivalent.

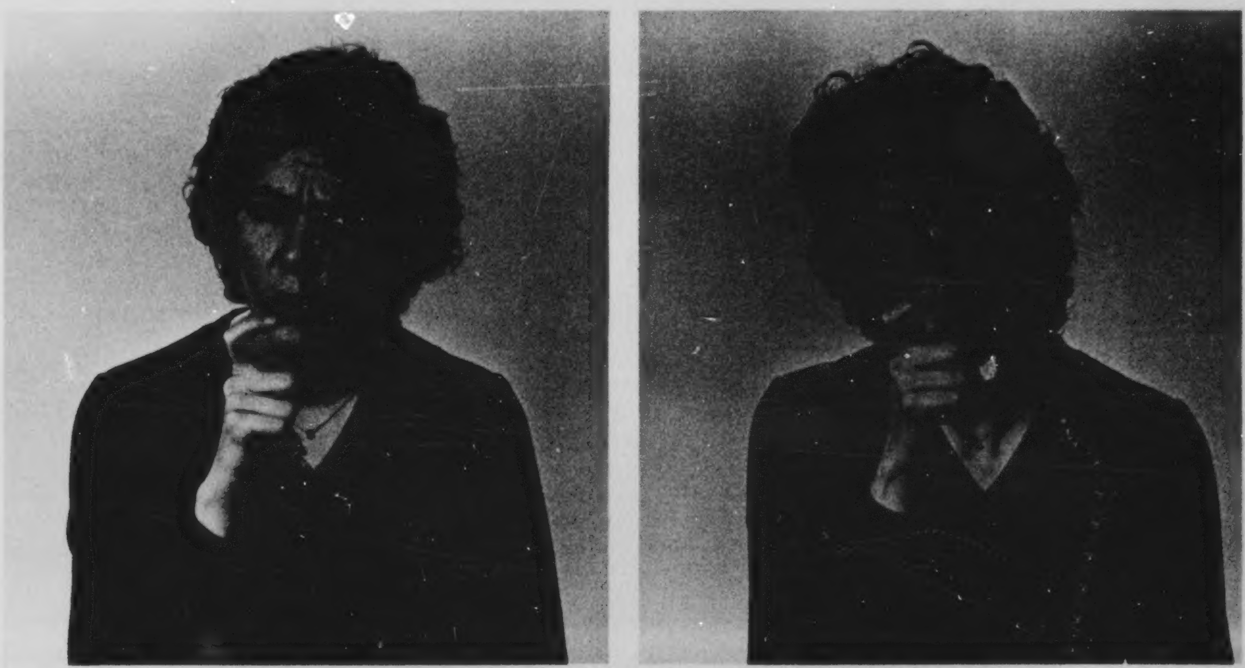
This opens up many exciting possibilities for real advances in our own understanding of memory, since there is now a precisely circumscribed system over which memories must pass. We can ask what direction the transfer is going in: Does the memory remain in the "seeing" half of the brain, where it is somehow accessible to the other half? Or is the memory—via the connecting pathway—actually formed, redundantly, in the "nonseeing" half of the brain as well? In any event, the source and nature of the activity in the connecting pathway are clearly related to memory processes. And that discovery is leading to much greater precision in defining those processes.

As something of a bonus, the method Doty uses also permits analysis of the different ways that the brain's two halves process certain kinds of complex stimuli—a situation exceedingly evident in human beings and so far strangely absent in monkeys. The experimental arrangement will determine whether one half of the brain in monkeys is better than the other for registering one or another type of visual information. No such difference has yet been discerned with stimuli of pure color or complex form, but it may arise when identification of faces or geometric arrangements is required.

Nonmanual Behavior in Sign Language

Twenty years ago the conventional wisdom was that sign language, used by deaf people, was not a legitimate language but an inferior system of gesturing that deaf people should suppress. When NSF made a grant to William Stokoe of Gallaudet College to do research on American Sign Language (ASL), critical letters appeared in the ***Washington Post*** reflecting the prevalent attitude.

Stokoe's early research resulted in a dictionary of ASL; it showed that ASL signs were structurally analogous to the words of spoken language in fundamental ways. These findings stimulated scientists in a number of research centers to investigate the properties of ASL more thoroughly. As those properties—syntax, morphology, dialect variation, psychological processes of production and comprehension—were explored, the outcome was the same: Once you get beyond the ways that a language of the hands *must* be different from a



"Body" sign language. Scientists have recently shown that facial expressions and other nonmanual signals play a key role in communication among the deaf and others who use American Sign Language (ASL). Here a woman makes the sign WHO. At left, the manual sign is accompanied by the nonmanual sign for "wh" word questions (e.g., "Who did it?"). At right, the sign occurs with the nonmanual signal for rhetorical questions (e.g., "And who did it? The butler?"). Thus syntax is conveyed by body movements—of the eyes, face, head, torso, etc.—other than those the hands make. This research reveals an aspect of sign language that went unnoticed before.

spoken language, ASL has all of the important properties of spoken languages.

This has been a discovery of the first importance scientifically because it has offered researchers a unique perspective on the underlying properties of language. It has been no less important in the deaf community. Educational practices in teaching deaf children have been profoundly affected by the new awareness that ASL is a legitimate language. Children are being encouraged to use their own language to learn, instead of one that is largely inaccessible to them.

William Stokoe has continued his research on sign language. Most recently he has been collaborating with Charlotte Baker, also of Gallaudet College, on a study of linguistic expression in ASL which uses parts of the body other than the hands. The significance of the hands in signing is of course central, and manual behavior has naturally enough been the focus of most research. Stokoe and Baker have shown, however, that facial activity and head position have definite linguistic functions in ASL.

Sentence types are distinctively marked nonmanually. The grammatical signal for a question, for example, consists of raised eyebrows, widened eyes, and often a tilting of the head or the whole body forward, while the signs for the words in the question are being produced. The same sequence of signs without the characteristic facial activity would not be understood as a question. Nonmanual behaviors also indicate relative clauses, conditionals, rhetorical questions, and even the subject of the sentence.

Now that ASL has been established as a genuine language, research like that by Stokoe and Baker helps us to understand the ways in which it is special. Spoken language has intonation patterns—changes in the pitch and stress levels that signal important matters such as sentence type. These are not available to sign language, which has replaced them with behaviors appropriate to the visual modality. Once again, linguistic science is given a new perspective for studying questions of central importance. Teachers of deaf children, moreover, can now be made aware of an extra dimension in their student's language—one that was previously unnoticed.

Social and Economic Sciences

The social and economic sciences are the chief sources of a vital accumulation of knowledge about human institutions and behavior, embracing groups as large as nations and as small as families. Research over the past decade has led to more understanding of how the economy works; how societies and individuals organize themselves politically, legally, socially, and spatially; and how they change. The process of change—what causes it, how it happens, and what its effects are—is a continuing theme and major focus for the social and economic sciences.

In 1982, as in previous years, the Foundation supported several projects that produced results of long-term scientific significance. Others yielded findings of more immediate relevance to current societal concerns. Both types of studies share several essential features: (1) the search for general patterns and principles that extend beyond the particulars of a specific time and place, (2) dependence on reliable and reproducible data that describe institutions and the way they run, and (3) the systematic test of general principles on the basis of appropriate and reliable data.

These characteristics define the principal research tasks for the social and economic sciences—namely, to develop appropriate theory and concepts leading to testable hypotheses, to improve analytical tools and techniques, and to build better and more comprehensive data resources. The products of these endeavors enhance our ability not only to discern and measure social change with accuracy but also to understand it at a deeper level and to anticipate it. Examples of this research are described here.

Economic Change and Family Life

Broad cyclical swings in the American economy have occurred historically and continue to be a part of contemporary life. These economic fluctuations often force families to face abrupt changes in their personal economic circumstances, depending on the availability of credit, jobs, family resources, and other factors.

NSF has supported studies of how families adapt to social and economic changes and the long-run effects of these experiences for parents, children, and the family unit. This research often requires a long-term investment to follow families and especially children from early development through later life. But the work has vastly increased our knowledge about family adaptation and the impact of economic deprivation on child development and later adult functioning. Some of these findings are expected; others are surprising.

Using data from two of the longest continuous-study files on children and their families, Cornell's Glen Elder and his many collaborators have analyzed the legacy of the Great Depression over the 17-year period from 1960 to 1977. They addressed early development and adult experience in samples of children born in Oakland, California in 1920-21 and in Berkeley, California in 1928-29.

The studies document dramatic changes in the domestic and economic roles of family members. Mothers and older male children took responsibility for contributing to the family's income and budget management as they moved into the labor force; older daughters typically played a major role in running households. In contrast, the father experienced a loss of power in the family, and the effectiveness of control by both parents dropped under conditions of economic deprivation.

Stress and conflict in the family increased with economic hardship. However, if parents were relatively close before a loss of income, such hardship enhanced the children's relationships with both parents. But when coupled with marital discord, deprivation sharply increased children's hostility toward the father while strengthening the relationship between mother and daughter.

The consequences of economic hardship for children clearly depended on their sex and age during the Depression. Young children growing up in the 1930s exhibited the greatest developmental problems; adolescents fared better. In social/psychological assessments, boys from deprived families were found to have lower aspirations and self-esteem and less self-direction and assertiveness than boys raised in better economic circumstances. And despite comparable ability, the scholastic performance of deprived boys fell below that of boys in more affluent families. By contrast, girls from deprived families displayed the competence that so many of their mothers exhibited during economic hardship.

Reflecting the resilience of human personality, however, developmental problems could be surmounted between adolescence and midlife. For men, early entry into the labor force, military service, and delayed marriage seemed to give them essential time for personal development; this allowed them to overcome their handicaps as children of the Depression. Even so, the enduring consequences of economic hardship are found mainly in men's values. At midlife, men with deprived childhoods were more likely to value mutual understanding in marriage and security in family life than one would predict on the basis of their current adult situation or early class status.

From these and other findings we begin to understand how macroeconomic changes affect family life. It is clear that the nature of economic change, its severity and duration, establish a unique context. Nonetheless, patterns of behavior have been found and these suggest a general model of family adaptation and outcomes. Future research that follows individuals through life will look further at family adaptation in relationship to other social and economic changes.

Trends in Time Use

One of the chief aims of the National Time-Allocation Data Series, collected by the University of Michigan's Institute for Social Research, is to measure trends in the way people apportion their time among various activities. Such trends may reflect important and otherwise unobservable social and economic phenomena. Like census data, these measurements are indicators of social change.

This series currently consists of surveys made in 1965-66 and 1975-76, plus one completed in 1982 on a subset of the respondents interviewed in 1975-76. The latter gives longitudinal data, making it possible to do analyses that monitor, to an extent never possible before, changes in the way American households allocate time. The 1981-82 data were collected too recently to produce any fine-grained analyses of current trends or underlying societal processes. However, some broad conclusions are suggested.

The results reflect data for the 10 activity categories commonly used in time-use studies since the mid-1960s. All of the categories include associated travel time; thus commuting time is part of work in the marketplace ("market work"). The data for both males and females show average weekly hours in 10 major activities for 1975-76 and 1981-82, along with differences between the two periods (see table).

Even though the statistics represent only first calculations from the 1981-82 study, they suggest some interesting changes. These reflect a marked difference from the pattern of time-series changes shown between the mid-1960s and the mid-1970s. The most interesting results show up in the market-work and household-production categories.

Hours spent at market work show a slight increase for males—due mainly to more time spent on second jobs—and a more sizable increase for females. This is probably a result of both higher participation rates among women as well as a shift from part- to full-time work.

The household-production categories reveal a very interesting phenomenon: Men are clearly doing more household activities than before, and women on the average are doing less. The most dramatic change is the reduction of 2.7 hours—more than 10 percent—in the household-work category for women, coupled with a slight increase in that category for men. Both men and women show somewhat more hours spent in child care. In conjunction with the decline in numbers of children, this suggests a nontrivial increase in hours spent per child. And in the services and shopping category, men show a substantial increase while women spend about the same amount of time.

These changes all move in the direction of equalizing the market-work and household-production activities of males and females. It is still true that males spend many more hours working in the marketplace than do females, and the latter spend many more hours in household production than males do. But the gap is narrowing in both cases. This contrasts with the results of previous analyses, which showed no evidence that a shift of this sort was under way.

Other interesting findings include a shift away from television viewing toward other

Average Weekly Hours Spent in Major Activities, 1975-76 Compared to 1981-82, Individuals Between 25 and 64

Major Activity Category	Males			Females		
	1975-76	1981-82	Difference	1975-76	1981-82	Difference
Market work	43.1	43.7	+0.6	20.8	23.7	+2.9
Household work	7.9	8.1	+0.2	21.2	18.5	-2.7
Child care	1.5	2.0	+0.5	4.6	5.2	+0.6
Services, shopping	3.6	4.5	+0.9	6.6	6.6	--
Personal care (includes sleep)	75.6	73.4	-2.2	77.2	75.6	-1.6
Education	1.0	0.9	-0.1	0.7	0.6	-0.1
Involvement with organizations	2.4	2.8	+0.4	3.1	3.4	+0.3
Social entertainment	6.9	6.6	-0.3	8.2	8.8	+0.6
Active leisure (sports, etc.)	5.0	5.1	+0.1	4.4	4.6	+0.2
Passive leisure (includes television viewing)	21.0	20.9	-0.1	21.3	21.0	-0.3
Total	168.0	168.0	--	168.1	168.0	-0.1

Details may not add to totals due to rounding.

"passive" leisure activities, such as reading, listening to tapes or records, and talking on the telephone. Television viewing time dropped by about an hour per week for males and almost that much for females.

The Theory of Industry Structure

In his 1981 presidential address to the American Economic Association, William Baumol reported on a major development (termed by some a revolution) in the theory of industry structure. A book on the new theory coauthored by Baumol, of both New York and Princeton Universities, John Panzar at Bell Laboratories, and Robert Willig at Princeton was published the following spring.

Conventional analysis of the determination of output and prices typically assumes that the size and number of firms in particular industries are set by forces outside the economic activities being studied. By contrast, the unified theory developed by the Baumol team treats industry structure as a variable set by economic forces simultaneously with the pricing, output, advertising, and other decisions of the firms involved.

Many theories focus on small single-product firms, whereas the reality is that virtually all firms produce and sell more than one good or service. By bringing the multiproduct enterprise (including the very large firms) squarely into the framework of microeconomic theory, the authors have made a major contribution toward generalizing microanalysis. They have also greatly increased its applicability to the real world.

The power of potential competition to extend the positive effects of active competition is the book's central theme. To investigate the limits of this power, Baumol and his collaborators formulated the concept of contestable markets—those in which potential competition is unimpeded by frictions or by entry or exit costs. This generalization of the traditional concept of perfectly competitive markets reduces the number of assumptions needed to obtain the usual efficiency results.

With contestability theory it is no longer necessary to assume that efficient outcomes occur only when there are a great many actively producing firms, each basing its decisions on the belief that its own output is too small to exert any effect on price. What drives contestability theory is the opportunity for what is called costlessly reversible entry. Where such entry is possible, efficient outcomes are shown to be consistent with the relatively large scales of operation that characterize many industrial technologies.

When entry and exit are completely free, efficient incumbent monopolists and oligopolists may in fact be able to prevent entry. But they can do so only by offering the very benefits competition would bring. Otherwise, they are rendered instantly vulnerable to hit-and-run entry.

The authors do not argue that most markets are perfectly contestable, although many may be approximately so. But they do maintain that prices and industry structure in most markets can be usefully compared to what they would be if those markets were perfectly contestable. Many of the implications of the contestable market standard are consistent with policy conclusions long held by economists. For example, the new analysis reinforces the view that any proposed regulatory barrier to entry must start off with a heavy presumption against its adoption.

The essential lesson is that regulators should adopt policies that enhance the contestability of markets. Thus not only increased freedom of entry but also of exit should be fostered. In addition there may well be a need to regulate access rules—say, by requiring leasing or shared use of sunk-cost facilities.

The new theory also furnishes some surprising insights, especially in the antitrust sphere. There it can be valuable in turning the judicial process away from exclusive reliance upon traditional market-share measures to evaluate mergers and toward reliance on the degree of structural contestability in the industry. Thus a history of absence of entry in an industry and a high concentration index may be signs of virtue, not of vice, as is usually supposed. This will be true when entry costs, as defined by Baumol and his collaborators, are negligible. Under such circumstances, the effects of efforts to change the industry structure by precluding mergers or by dissolving large firms must be regarded as undesirable and antisocial.

Information Science and Technology

Material and energy resources are the physical capital of our society, information resources its intellectual capital. NSF works to increase understanding of the scientific laws that deal with organizing, maintaining, and managing bodies of information. Another NSF goal is to discover and formulate rules for the generation, transmission, and use of information. The Foundation does all this by supporting research that:

1. Adds to our fundamental knowledge base about information and how it is transferred.
2. Expores the use of new information technology.
3. Helps us understand the impact of proliferating information technologies on social organization, scientific research, and business management.

NSF is the chief federal supporter of basic research in this area. This contrasts with mission-oriented information research aided by the Department of Defense, and with work by the National Library of Medicine, which focuses on improving medical information systems.

Information science draws upon related research supported by NSF in computer science, electrical and computer engineering, cognitive psychology, linguistics, and economics. There is close coordination among all these Foundation programs.

Progress in computer and electrical sciences stimulates information science and technology. In particular, new instrumentation and capabilities—such as greater capacity for storing, manipulating, retrieving, and communicating information—aid new approaches to long-standing problems in the information area. But such advances also create new challenges. For example, the ability to store the contents of the Library of Congress in a one-inch cube would solve storage problems, but that information would be totally inaccessible without appropriate structure and access methods.

Major questions under investigation include these:

- What are the best ways to organize

very large and complex databases, natural language, and other information systems?

- What is the relationship between language and knowledge representation and the use of natural language for communicating with machines? What are the abilities and limitations of people as information processors?
- What is the role of information in the economy? What are the economies of scale in producing, distributing, analyzing, and evaluating information?
- What factors determine the social and economic impact of information technology?

The two projects described here are examples of recent NSF-supported research.

The Possibility Theory

The representation of meaning is a major problem in developing systems that can deal with the full range and richness of natural language, including the imprecision and lack of specificity that are intrinsic to communication among humans. Lotfi Zadeh of the University of California, Berkeley is working on a conceptual framework to deal with this problem. The goal is to develop a comprehensive theory of natural languages, especially for the representation of meaning, knowledge, and belief.

Zadeh starts from the point of view that no mathematical theory based on two-valued (true-false) logic can mirror the elasticity, ambiguity, and context dependence that set natural languages so far apart from synthetic models. As an alternative, he has developed a meaning-representation language called PRUF, which uses what might be described as *possibility theory*. Instead of the two possible values permitted by true-false logic, through possibility theory one can represent the meanings of fuzzy quantifiers such as ***many, most, few***, and ***almost all***; modifiers such as ***very, more*** or ***less, quite, rather***, and ***extremely***; and fuzzy qualifiers such as ***quite true, not very likely***, and ***almost impossible***.

So far it is relatively easy to teach a human subject to translate from a natural language into PRUF but very hard to write a computer program that could perform similarly without human aid or intervention. Zadeh therefore is building on his early work, which focused on fairly simple propositions.

Basic research in information science, as exemplified in this project, will increase our understanding of the way information is represented and used in both brains and machines, in the contact between them, and in the abstract. It is only through such fundamental understanding that we can improve efficiency in storing, manipulating, retrieving, recoding, interpreting, and using information.

Information Technology: Graphics and Layout

Scientists at Stanford University have been studying the use of computer systems to generate, represent, and display both textual and graphic information. Working under Donald E. Knuth, the investigators are concerned primarily with the ***structure*** of such information in terms of two-dimensional layout. This could be the chapter/section/paragraph organization of a book, the schema of a data base, the syntax of a computer program, or the structure to be represented in a drawing.

Historically, the enormous growth of available computer power has suggested more and more ways to apply computer technology in preparing documents. Industry and academia have responded with a stream of tools, both hardware and software. But the functions of these tools have traditionally focused on distinct activities such as text editing, data entry, and typesetting, with little or no cross-application of concepts. Knuth hopes to develop a model to remedy this situation, making useful functions available from one activity to another.

Another area under investigation is ***graphic composition***. The generation and modification of graphic information have not received much scientific attention. True, there are ways for users to specify figures as collections of lines and dots. But there has been little study of figures as structured aggregates of shapes, so as to allow their isolation from any particular two-dimensional layout, for example. Still another area of activity is that of specifying layout via computers. Here the Stanford team has concentrated largely on typesetting systems.

Research like this is laying a foundation for the design of future systems to prepare documents. Among the results from Knuth and his colleagues are these:

- A large family of typefaces called "Computer Modern." These have already been used to prepare thousands of documents on a wide variety of machines.
- A programming language for the design of Chinese characters.
- A computer language to specify technical illustrations. In this language text and graphics are automatically adjusted to the layout of a page.
- Algorithms for optimal line breaking and pagination.
- Techniques to compress information a thousandfold, for efficient communication between a host computer and a primitive typesetting device.

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Astronomical, Atmospheric, Earth, and Ocean Sciences

4

These sciences focus on the characteristics of the earth, its atmosphere, and the far reaches of the universe. Their boundless spatial extent is matched by a time span that ranges from investigations of galaxies as they were 10 billion years ago to work on current weather and climate phenomena and volcanic eruptions. Besides satisfying intellectual curiosity, such studies enable scientists to predict environmental changes and hazards with greater accuracy. They also provide basic information on natural resources.

The Foundation helps advance knowledge in all areas of ground-based astronomy by awards to individual astronomers, funding for new instruments, and support of five national astronomy centers. Recent achievements include:

- Confirmation of the theory of pulsation in white dwarf stars.
- Chemical analysis of globular-cluster stars that are among the oldest in our galaxy.
- Observation of a radio source believed to be a black hole at the center of the Milky Way.
- Discovery of possible connections between sunspots and terrestrial weather.

Atmospheric sciences draw on knowledge from many fields of science and mathematics. In 1982 NSF supported atmospheric research through grants to academic institutions and contracts for the operation of two national centers.

Recent studies have yielded new knowledge of the possibly adverse climatic effect on the atmosphere of rising carbon dioxide levels. Other findings bear importantly on air-traffic safety problems, drought predictions for water-dependent regions, and the role of mountains in storm development.

The earth sciences, in which NSF supports the bulk of academic research, investigate the earth's evolution from its beginning to the present, its chemical and physical properties, and the processes that produce its characteristic features. Earth scientists also study the evolution of life as seen in the fossil record.

New achievements in the earth sciences, some of them implicit in the theory of plate tectonics, include:

- Discovery in coastal areas of the Pacific Northwest and New England of large "displaced terrains" that seem to have originated far to the south.
- Development of more accurate predictive capabilities in mineral exploration.
- Deduction (from measurements of frequency shifts in seismic waves) of the large-scale aspherical structure of the earth.

Ocean scientists in 1982 gave increasing attention to:

- Studies of the sea floor.
- Instrumentation for acoustic sensing of subsurface currents and water masses.
- Physical circulation processes of the coastal ocean.
- Processes controlling physical, chemical, and biological interactions at mid-ocean ridges.
- Deep-ocean sediments, especially studies relating to ancient climate.

New techniques and instruments enabled ocean scientists to produce detailed, real-time maps of the sea floor and to identify areas for specialized scientific study. Using the new tools, ocean scientists continued to make striking discoveries about deep-sea hydrothermal vents and their communities of unusual marine organisms. Based on hydrogen sulfide, the food chains found near active vents may give clues to early life on earth.

Table 4
Astronomical, Atmospheric, Earth, and Ocean Sciences
Fiscal Year 1981 and 1982

(Dollars in Millions)

	Fiscal Year 1981		Fiscal Year 1982	
	Number of Awards	Amount	Number of Awards	Amount
Astronomical Sciences*	225	$ 58.37	212	$ 59.10
Atmospheric Sciences*	486	69.27	477	70.34
Earth Sciences	516	27.86	540	29.49
Ocean Drilling Programs	20	22.00	17	20.00
Ocean Sciences	618	74.97	730	75.03
U.S. Antarctic Program	148	67.45	152	68.50
Arctic Research Program	66	5.81	78	5.90
Total	**2,079**	**$325.73**	**2,206**	**$328.36**

*Includes National Research Centers

SOURCE: Fiscal Years 1983 and 1984 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Several federal agencies, including NSF, support research in the arctic. For the antarctic, though, the President of the United States has reaffirmed the Foundation's responsibility for funding and managing the U.S. program there.

In Antarctica in 1982, paleontologists reached a goal that had eluded science for half a century—finding a fossil land animal. The find established that Antarctica was a land bridge between South America and Australia about 50 million years ago.

Other research in the polar regions advanced knowledge of global climate. In Antarctica, for example, satellites measured ice sheet elevation and unmanned stations monitored climatic circulation. In the arctic oceanographers measured heat passing through the main strait between the Atlantic and Arctic oceans, a flow that helps determine long- and short-term variations in the earth's climate.

Astronomy

Astronomy draws on the principles of physics and chemistry to investigate the universe. The past decade has witnessed impressive progress in astronomy, as we move toward an understanding of many puzzles and a realization of how diverse and awesome the universe is.

Quasars, astronomers now generally agree, are the explosively active nuclei of galaxies too remote for convincing detection even by the largest telescopes. Entire classes of galaxies may have experienced quasar outbursts. Theoretical investigations of gravitational singularities have established a connection between black holes and the laws of thermodynamics. Recent computer efforts to analyze the distribution of a million galaxies across the sky, along with attempts to determine the distribution of galaxies in depth, have opened a new branch of cosmology.

Observations of the same objects in different portions of the spectrum have become common. These observations give fresh insights into phenomena that once seemed beyond human perception. Through observations at infrared and radio wavelengths, astronomers can now probe the structure and chemistry of interstellar clouds, gauge the importance of supernova explosions and density-wave shocks to star formation, and begin to understand the origins of planetary systems. Many sources of x-rays and gamma rays are the products of gas accretion onto neutron stars or black holes, astronomers believe. They have deduced much about the evolution of stars into objects such as these.

For the exploration of new realms of space and energy, astronomy depends on instruments and detectors of ever increasing power, sensitivity, and resolution. The development of highly efficient electronic detectors has allowed optical astronomers to glimpse galaxies fainter, older, and more distant than ever before. New developments have made it more feasible, both technically and economically, to build much larger telescopes for optical and infrared work. Computers too have become fast and economical. They are now essential tools to reduce ever more rapidly accumulating data, process images of continually greater detail, and do increasingly complex theoretical calculations.

Still beyond the limits of current observational capability is the resolution of several critical problems. These include the formation and early evolution of galaxies, the energy source of seemingly faster-than-light motions in quasars, and the stellar motions and energetic processes in the cores of many galaxies and globular clusters.

The National Academy of Sciences has published a comprehensive program of recommended research, entitled *Astronomy and Astrophysics for the 1980s*. It sets forth opportunities, plans, and priorities for those two areas during the current decade.

The Foundation supports astronomical research at more than 140 universities, private and federally owned observatories, and industrial firms. It does this through research grants and by providing observing time at the observatories. Ground-based and theoretical studies of the composition, structure, and evolution of the sun, the solar system, stars, interstellar medium, and galaxies all receive funding. NSF also promotes the development of new instrumentation and computing capabilities to aid these studies.

Astronomers throughout the nation have access to telescopes, instruments, and facilities that are among the largest and most advanced in the world. They can observe in optical, infrared, and radio frequencies at the five national astronomy centers supported by NSF:

- The National Astronomy and Ionosphere Center in Puerto Rico.
- Kitt Peak National Observatory in Arizona.
- Cerro Tololo Inter-American Observatory in Chile.
- The National Radio Astronomy Observatory, with observing sites in West Virginia, New Mexico, and Arizona.
- Sacramento Peak Observatory in New Mexico.

In addition to aiding visiting astronomers, staff members at these observatories do their own research as well.

A New Type of Variable Star

Most stars whose brightnesses vary with time do so because of changes in their radius. These changes alter not only the radiating surface area but, more important, the density of the radiating surface layers. Most stars known to pulsate are rather luminous, typically white or yellow giants with brightness variations repeating in cycles on the order of days in length. Or they are red supergiants displaying much slower and less repetitive variations. Not until nine years ago, however, were variable stars discovered among white dwarfs, the ancient relics marking the end of stellar evolution for all stars no more massive than our sun.

White dwarfs are hot yet faint by virtue of their small diameters, which are comparable to those of planets. These stars have collapsed as the result of internal exhaustion of their hydrogen fuel through conversion to heavy elements. Since white dwarfs retain most of their original mass, they are quite dense. A typical cubic centimeter of their matter weighs 100 kilograms.

Though only some white dwarfs are observed to pulsate, all in a particular color range do. This implies that all white dwarfs pass through this phase at some time during their nearly expired lives, making them the most common type of variable stars. Such bodies are the best practical laboratories for tests of pulsation theories. Their high densities result in periods of only a few minutes, permitting many cycles to be witnessed in a single night.

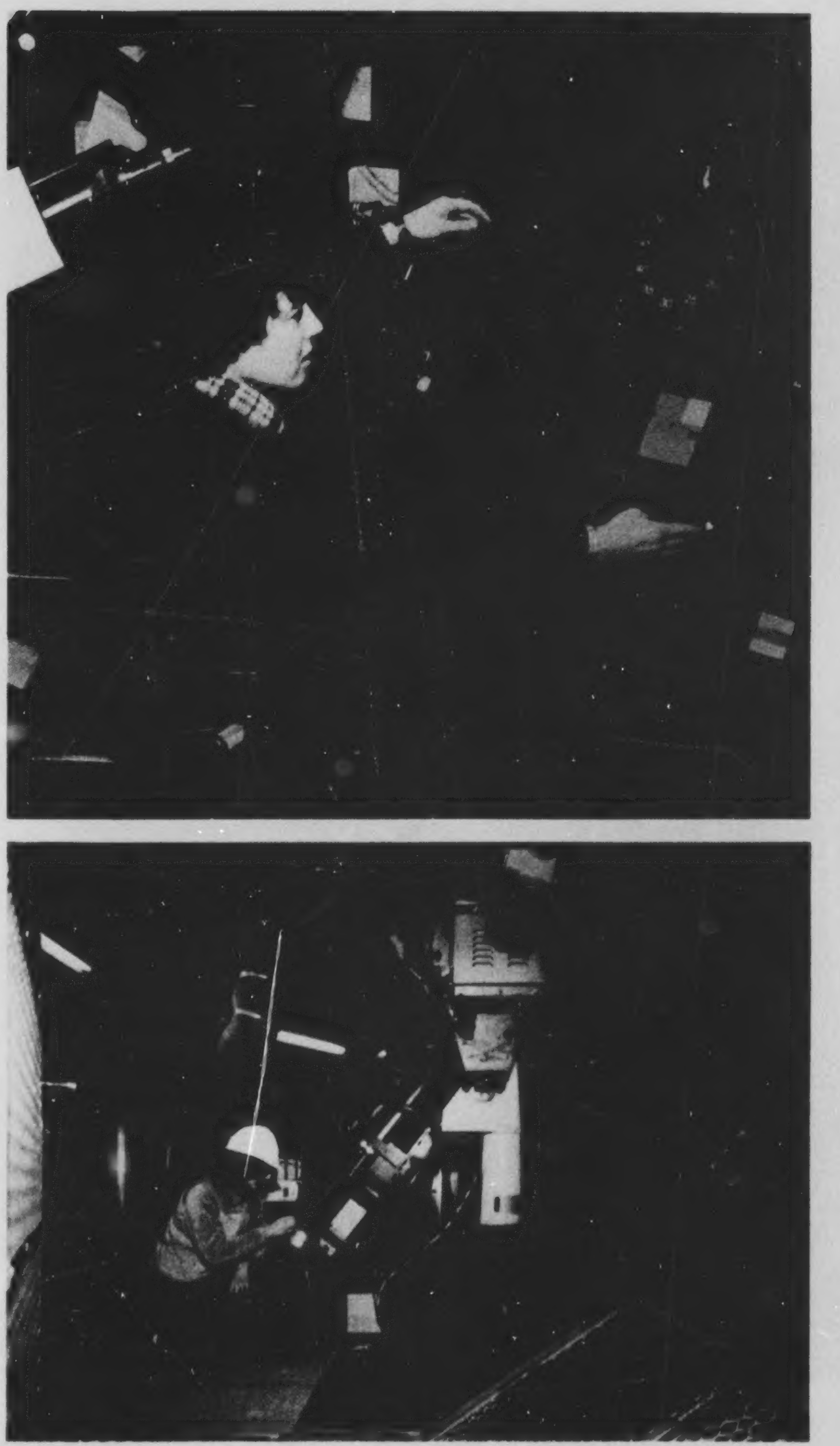
Despite the exhaustion of their internal hydrogen, most white dwarfs still have a residue of that element in their surface layers. Such is the case with the variables called ZZ Ceti stars. The surfaces of some white dwarfs, however, contain only helium. Donald Winget of the University of Texas predicted a year ago that helium-rich white dwarfs of a certain temperature (color) range should also pulsate. He and collaborators Edward Robinson and Edward Nather, also of the University of Texas, and Gilles Fontaine of the University of Montreal, turned a 91-centimeter telescope at the McDonald Observatory toward a star with the proper characteristics; they found that the object (designated GD 358) did indeed pulsate.

The star has a mass about 60 percent that of the sun, a radius about twice that of earth, and a surface temperature of roughly 22,000 degrees centigrade. It is the first type of variable star whose existence was predicted by theory prior to its discovery.

This finding is a direct confirmation of white-dwarf pulsation theory. Since the details of stellar pulsations are related to internal structure and composition, astrophysicists can now probe the interiors of white dwarfs in much the same way that geophysicists use seismic waves to study the interior of the earth. The probes may add significantly to our understanding of the late stages of stellar evolution and the early history of star formation.

The Chemistry of Globular Clusters

Among the most beautiful and fascinating objects in the sky are globular clusters, each consisting of hundreds of thousands of stars occupying a space about 100 light-years across. All the stars in a globular cluster must have formed at the same time from material of presumably uniform chemical composition, mainly hydrogen and helium. Thus any present differences in the stellar luminosity and temperature distributions among these clusters should reflect nothing more than their differing ages. Heavy elements build up in the cores of the stars from hydrogen through thermonuclear fusion.



Stellar research. Astronomers Catherine Pilachowski (top) and Judith Cohen adjust equipment on their telescopes. Pilachowski's is a 2.1-meter instrument at the Kitt Peak National Observatory; Cohen's is the five-meter telescope on Palomar Mountain. Recently these two scientists have done important work on globular-cluster stars. Their findings will help us learn more about stellar and galactic evolution.

Theoretical calculations reveal the stars in globular clusters to be among the oldest objects in our galaxy, setting a lower limit on the age of the universe of about 15 billion years. Thus globular clusters exhibit the most pristine surface compositions observable.

With the availability of sensitive new electronic detectors and large telescopes (such as the four-meter reflectors at Cerro Tololo and Kitt Peak), astronomers can now observe faint globular-cluster stars better than ever before. They can also analyze the stars' chemistry spectroscopically with unprecedented accuracy. Recently they have found a hundredfold difference in heavy-element abundances in globular clusters near the same age; these findings are yielding valuable insights into the early evolution of our galaxy.

Photometric observations at Cerro Tololo and Palomar Mountain have revealed large variations in the abundances of carbon and nitrogen among stars in the same cluster. This work was done by James Hesser and Robert McClure of the Dominion Astrophysical Observatory and David Hartwick of the University of Victoria. The behavior they observed, which is not seen elsewhere in the galaxy, has been confirmed photometrically and spectroscopically by Roger Bell of the University of Maryland, Robert Dickens of the Royal Greenwich Observatory, and Bengt Gustafsson of Uppsala University. They used data from Australia and South Africa.

Carbon and nitrogen are important in stars both because their line strengths are usually reliable indicators of luminosity and because these elements act as catalysts in the fusion reactions. In order for the carbon and nitrogen formed in stellar cores to affect stellar-surface compositions and spectra, these elements must be transported outward through each star by some unusual process that is perhaps associated with rapid core rotation. It is also possible that, contrary to accepted theory, globular clusters may have been born with significant chemical inhomogeneities.

Further complicating the puzzle are discrepancies noted between abundances deduced spectroscopically and those inferred from the colors of globular-cluster stars. These discrepancies, found by Catherine Pilachowski of Kitt Peak, Judith Cohen of Caltech, and their respective colleagues, may indicate that globular clusters are even poorer in heavy elements than once thought; this has serious implications for our understanding of stellar and galactic evolution. Clarification of these matters may come from observations of very old, faint stars in our galaxy—and of globular clusters in other galaxies—with the space telescope of the National Aeronautics and Space Administration (NASA) and a huge, ground-based instrument called the National New Technology Telescope. The latter has ony been proposed at this writing.

The Galactic Center

The center of our Milky Way galaxy, lying in the constellation Sagittarius, is one of the brightest radio sources in the sky. It was the first extraterrestrial radio source detected (in 1932), but for years it remained mysterious. Radio telescopes lacked the resolving power to reveal many details, and clouds of gas and dust in the galactic plane blocked viewing by optical telescopes.

Infrared radiation does penetrate this interstellar material but is absorbed by water vapor in the earth's atmosphere. During the past few years, however, telescopes sensitive to infrared wavelengths have been flown aboard aircraft and operated at high, dry mountain sites like Mauna Kea in Hawaii. These instruments have revealed a ring of silicate dust in the core of our galaxy at a temperature that might be explained by the presence of a heat source like a cluster of hot, young stars. But such a cluster would have to occupy a volume about one light-year across—far more compact than the usual congregation of stars.

Recently, Robert Brown of the National Radio Astronomy Observatory and Kenneth Johnston of the Naval Research Laboratory have succeeded in observing the galactic center. Using the Very Large Array (VLA) telescope, they have discovered, at the center of the dust ring, an exceptionally small and luminous radio source whose core has a remarkable, spiral-like pattern. The gas in the spiral pattern seems to flow outward from a still smaller source at the rate of about one solar mass per millennium and at velocities in excess of 350 kilometers per second. The central source varies strongly in intensity on a time scale of about a day. Since dynamical effects cannot propagate faster than light, this variation in intensity indicates that the object is comparable in size to our solar system.

The spiral pattern of opposing gas jets immediately suggests similar forms glimpsed in quasars by a high-resolution radio technique called very long baseline interferometry (VLBI). Quasars are hundreds of times more luminous than our entire Milky Way. This prodigious energy output is best explained as the by-product of an infall of gas and dust from a rotating disk to a central, supermassive black hole embedded in an otherwise normal galaxy. Excess material may be expelled along the axes of such a disk, and a spinning black hole would cause the disk to wobble, producing the spiral jets we see. Thus the centers of most galaxies, including our own, may well contain similar, though less massive, objects.

On the other hand, some galaxies show no evidence of central black holes. George Rieke of the University of Arizona has studied the infrared spectra of stars within about three light-years of the galactic center. He has suggested that our galaxy's central object may be nothing more than a newly formed cluster of supergiant stars. Resolution of the mystery surrounding the central objects of galaxies and quasars may have to await such new radio telescopes as the proposed very long baseline array, which will span the entire country.

Solar Magnetism

Nearly 140 years ago a German amateur astronomer discovered the 11-year solar cycle. During this cycle sunspots appear at intermediate latitudes on the sun's photosphere, drift toward the equator, and disappear. Several other solar phenomena occur in the same areas and vary in frequency and size according to the same period; they include bright chromospheric patches (plages), filaments, flares, and prominences. These centers of activity represent the emergence of one or more loops of magnetic field lines.

The solar atmosphere is strongly ionized, and the magnetic fields and ionized gas are locked together. A sunspot appears dark because it is a localized region of relatively cool gas trapped in a strong magnetic field. Such a field represses the convective outflow of energy but is eroded by the rising gas and eventually merges with a general network corresponding to the supergranular pattern of rising convective cells. Coupling between this convective flow and the rotation of the sun is thought to generate a global dynamo; its oscillation between two field geometries and magnetic polarities results in the solar cycle.

Scientists in recent years have uncovered several possible connections between the sun's activity cycle and the earth's weather. Historically, sunspots virtually disappeared during Europe's little ice age of the 17th century. In more recent times, droughts have occurred in the western and midwestern United States in every other sunspot minimum. The earth's climate is quite sensitive to changes in the sun's total luminosity. Since more than half the energy the sun radiates into space results from convective transport, the effects of magnetic fields on solar convection may have important consequences for all life on earth.

The possibility of variations in solar luminosity has intrigued scientists for decades. Until recently, though, uncertainties in the wavelength transmission of the earth's atmosphere and in the wavelength sensitivity of radiometric detectors precluded discovery of those variations. The first detection came as a correlation between previously unknown fluctuations in solar luminosity, found by NASA's Solar Maximum Mission satellite, and the passage of sunspots across the solar disk.

The next detection was made from the ground by William Livingston of Kitt Peak; he found a drop of six degrees centigrade since the previous sunspot minimum in 1975-76. Livingston showed for the first time that the sun's outflow of energy is partially controlled over the entire surface by its magnetic field; the finding confirms a theory proposed in 1980 by E. A. Spiegel of Columbia University and N. O. Weiss of the Harvard-Smithsonian Center for Astrophysics. Livingston monitored the sun's temperature with the McMath Solar Telescope, the largest such instrument in the world, which is equipped with a Fourier transform spectrometer.

National Astronomy and Ionosphere Center

NAIC is operated by Cornell University under contract with NSF. The center supports research programs in radio astronomy, planetary radar astronomy, and atmospheric science. NAIC's principal instrument, located near Arecibo, Puerto Rico, is a 305-meter antenna, the world's largest radio/radar telescope. NAIC also operates two remote sites—one 11 kilometers north of the observatory, where a 31-meter antenna is located and the other 17 kilometers north of the main site and home of the High-Frequency Ionospheric Heating Facility.

Several receiver systems have undergone recent improvements. Most important was the installation of a dual-channel cryogenic GaAsFET receiver, which has doubled the system sensitivity at the 21-centimeter hydrogen line and greatly increased both the quality and quantity of the hydrogen-line data. The receiver made some observations feasible for the first time and quadrupled the telescope's "speed" by reducing the time required for other observations. Another improvement in sensitivity came from the installation of dual-channel, 2,380-megahertz maser receivers at the main telescope and at the 31-meter antenna.

Kitt Peak National Observatory

KPNO is operated under contract with NSF by the Association of Universities for Research in Astronomy, Inc. (AURA), a nonprofit consortium representing 16 universities in the United States. As the nation's main center for optical and infrared astronomy research, KPNO provides U.S. astronomers access to the large telescopes, auxiliary instrumentation, and support services needed for observational and theoretical research in galactic, stellar, solar, and planetary astronomy.

Besides operating 12 telescopes, KPNO offers sites and services on Kitt Peak for six more telescopes operated by other institutions. Its four-meter Mayall reflector is especially well equipped, and the McMath Solar Telescope is the largest such instrument in the world.

The observatory is located 84 kilometers southwest of Tucson, Arizona; it has extensive facilities, including workshops, a dining room, and dormitories, in addition to telescopes and auxiliary instrumentation. The KPNO Tucson headquarters, adjacent to the University of Arizona campus, has staff and visiting-astronomer offices, a computer center, and extensive engineering and technical facilities for the design and fabrication of telescopes and instrumentation.

KPNO also has important programs in detector development, optical coatings, and diffraction gratings; these benefit the entire astronomical community. As a result of its wide capabilities, Kitt Peak participates in the technology development program for the National New Technology Telescope. This instrument, of the 15-meter class, will be the principal ground-based project for U.S. optical and infrared astronomy research in the next decade.

Cerro Tololo Inter-American Observatory

Like KPNO, Cerro Tololo is run by the Association of Universities for Research in Astronomy under contract with the

Electronic detector in action. This photograph of the spiral galaxy M 64 was taken with an exposure time of only 10 seconds, using Cerro Tololo's four-meter telescope—newly equipped with a charge-coupled device. M 64 lies 25 million light-years away in the constellation of Coma Berenices. The device—a product of Kitt Peak's effort to develop better instrumentation—has made it possible for astronomers to observe at much greater magnitudes than before.

Foundation. This observatory's seven optical telescopes are the only ones generally available to U.S. scientists for studying the southern skies. They include a four-meter reflector, the Southern Hemisphere's largest and a twin to the KPNO Mayall telescope.

CTIO headquarters are in the coastal town of La Sereña, Chile, some 80 kilometers by road from the mountain site of the telescopes. The latitude of 30 degrees south and the exceptionally good atmospheric conditions over Cerro Tololo furnish ideal conditions for the study of such important Southern Hemisphere objects as the Magellanic Clouds and the central regions of our own galaxy.

Observing capabilities at CTIO have been greatly enhanced by the introduction of a charge-coupled-device camera system at the prime focus of the four-meter telescope. A product of KPNO instrumentation development, the system has a peak sensitivity near a wavelength of 6,000 angstroms—with some usable response below 4,000 angstroms and above 10,000 angstroms. How faint an object the camera can observe depends on such factors as sky brightness and atmospheric transparency, but in practice it has been possible to reach 25th magnitude with exposure times of one hour. This is two magnitudes fainter than has ever been reached photographically with long exposures at the CTIO four-meter telescope.

National Radio Astronomy Observatory

NRAO is one of the world's principal centers for radio astronomy. Operated by Associated Universities, Inc., NRAO has telescopes at three sites; its headquarters and a data-processing center are in Charlottesville, Virginia.

The two single-dish (91-meter and 43-meter) telescopes at Green Bank, West Virginia, are heavily booked by observers, whose interest in their use has risen since the implementation of more sensitive receivers. Observations can be made at practically any wavelength in the range from a centimeter to a meter. Pressure has increased for use of the 43-meter telescope for programs in very long baseline interferometry (VLBI), and there has been increasing interaction with the European VLBI network.

The Very Large Array (VLA) near Socorro, New Mexico provides a unique combination of high sensitivity and resolution for radio astronomy observations. Its 27 antennas are routinely used in different location patterns and at the four standard frequencies for continuum and spectral-line observations. An active effort continues to improve the VLA computer system's capacity to collect and analyze data.

On Kitt Peak, the third site, the surface of the 12-meter telescope is being improved at this writing, to allow observations to wavelengths as short as one millimeter. Under evaluation is the performance of new receivers for the one-millimeter-wavelength atmospheric window; these receivers should be ready for observations when resurfacing is completed.

Sacramento Peak Observatory

SPO is one of the world's leading solar observatories. It is located at an elevation of 2,760 meters in the Lincoln National Forest in New Mexico, on one of the best coronal observing sites in the continental United States. Thus SPO enjoys unusually good observing conditions, including extremely clear and unpolluted skies.

SPO has a number of unique solar research facilities and is a leader in applying advanced technology to solar observations. Its Vacuum Tower telescope produces very high resolution solar images, revealing the finest details in the solar atmosphere observable from the ground. An impressive array of auxiliary instruments permits extremely accurate measurements of velocity and magnetic fields in the sun's atmosphere.

Both SPO staff and scientific visitors pursue an active and diverse program of observations and theoretical studies. These include wave motions and oscillations in the solar atmosphere and the physical structure of sunspots and magnetic fields in them. SPO scientists have recently begun new research in solar/stellar astrophysics, using the sun as a basis for studying solar-type phenomena in a broad range of stars.

Atmospheric Sciences

Atmospheric science is a discipline that combines knowledge from physics, chemistry, mathematics, and other sciences to improve understanding of the earth's atmosphere—from the planet's surface to outer space. Through seven grant programs and support of the National Center for Atmospheric Research and the National Scientific Balloon Facility, the Foundation supported basic research on a wide range of subjects in fiscal year 1982.

Among the areas covered were the physics, chemistry, and dynamics of the earth's upper and lower atmosphere; physical processes in the troposphere and stratosphere, which will help explain general atmospheric circulation; the physical basis of climate; and climate processes and their variations, as well as smaller-scale, shorter-term phenomena leading to more knowledge about weather.

The nation's universities contain the richest intellectual resources for the study of atmospheric phenomena, and NSF continues to be the chief supporter of academic research in the atmospheric sciences. In fiscal year 1982, Foundation grants put special emphasis on:

- Meteorological processes with horizontal dimensions of 10 to 1,000 kilometers, including research that will undergird weather-modification activities.
- Development of methods and instruments to determine (1) the sources and sinks of trace substances in the atmosphere and (2) their chemical, dynamic, and energetic effects on the atmosphere and on one another.
- Studies of ocean-atmosphere and ice-land coupling processes. These will help us understand and model the climate system.
- Completion of the incoherent scatter-radar longitudinal chain to study the energetics of the upper atmosphere.

National Center for Atmospheric Research

NCAR achieves its mission—to increase fundamental knowledge of the atmosphere—by (1) developing and providing major research facilities and related services for the atmospheric sciences community, and (2) planning, coordinating, and doing research that requires long-term collaboration among scientists at NCAR, universities, and other laboratories.

The Foundation supports NCAR through a contract with the University Corporation for Atmospheric Research (UCAR), a consortium of 49 universities. NCAR is located in Boulder, Colorado and has a solar observing station at Mauna Loa, Hawaii. The University Corporation also operates the National Scientific Balloon Facility at Palestine, Texas. NSBF serves a community of investigators who use high-altitude balloons for scientific research in high-energy astrophysics, solar and plasma physics, and atmospheric sciences. Federal support of NSBF is being transferred from NSF to the National Aeronautics and Space Administration (NASA).

Current major research efforts at NCAR are in atmospheric analysis and numerical weather prediction, including climate studies and oceanography; atmospheric chemistry and aeronomy; solar research and solar-terrestrial interactions; and convective storms. The center develops and provides advanced computing facilities, aircraft equipped for meteorological research, and observing equipment such as Doppler radars for sophisticated weather measurements. NCAR also makes it possible for graduate students and scientists to visit the center and participate in collaborative or individual research.

Joint Airport Weather Studies Project (JAWS)

The field phase of this major three-year experiment took place near Denver, Colorado in the summer of 1982. The study focused on low-level wind-shear conditions during severe thunderstorms—in particular the intense downward and outward gusts of air (microbursts and downbursts) involved in a number of aircraft accidents and near-accidents during takeoffs and landings. Earlier work had clearly shown that the distances between radars and surface meteorological stations would have to be decreased if a significant fraction of downbursts were to be observed. JAWS developed from this finding, with an expanded application to aircraft safety. The Stapleton Airport near Denver was chosen as the field site because it experiences many summer thunderstorms.

Measuring the sun. Scientist Timothy Brown checks NCAR's solar diameter instrument. This reflecting telescope projects the sun's image into sensors that daily record both the horizontal and vertical diameter of the sun. These measurements will tell atmospheric researchers whether the sun varies in size and how such a change affects the earth's climate. Brown led the team that developed this instrument.

More than 100 U.S. and British university and government researchers collaborated in the field phase of JAWS. Basic research observations and findings have already been used to improve local, short-term weather forecasts in the Denver area and to prepare severe-weather advisories for the National Weather Service. In addition, JAWS investigators have used the field work to test and compare various severe-weather detection, warning, and observing systems.

The field operation involved coordination of a sophisticated network of observing systems. Managed by NCAR (John McCarthy and James Wilson) and the University of Chicago (Theodore Fujita), JAWS is funded mostly by NSF, with some monies and/or technical support coming from three other federal agencies. Participating institutions were Colorado State University, the Massachusetts Institute of Technology, the University of Wyoming, the University of Tennessee Space Institute, and the United Kingdom's Royal Signals and Radar and Royal Aircraft Establishments.

Wind-shear profiles derived from JAWS will be used in flight simulation training for airline pilots. They are also being made available to airlines and aircraft manufacturers for evaluating aircraft safety and performance. Several national news stories emphasized the experiment's air-safety features after the crash of Pan Am Flight 759 in New Orleans on July 9, 1982.

Microbursts have a short life span (2-20

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JAWS equipment. Project leader John McCarthy monitors a Doppler radar display console in the operations control room at NCAR. JAWS (Joint Airport Weather Studies) is an international effort to gather and evaluate information about the causes of microbursts, or low-level wind-shear phenomena. This research will improve systems to detect severe-weather hazards and warn aircraft pilots about them.

minutes) and occur over a small geographic area of up to four kilometers. Microburst-related events happened often during the summer 1982 program, and JAWS investigators were able to gather a rather large and useful set of data.

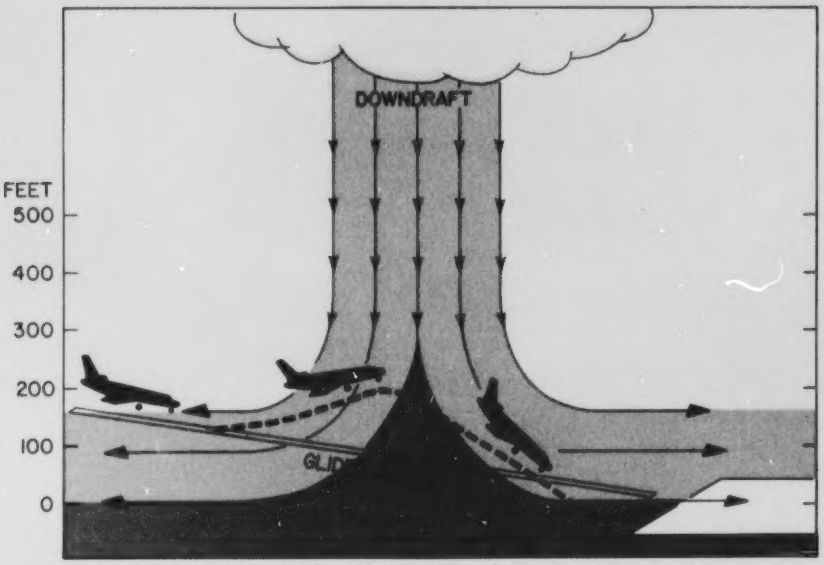
Preliminary results from the JAWS research seemed to confirm the meteorological structure of downbursts as first observed during a 1978 project. Nevertheless, these early JAWS results did not suggest that unique visual characteristics, such as the distribution of clouds and precipitation, are associated with specific downbursts. They did seem to support the theory that the evaporative cooling of the air produced by falling raindrops may not be the only mechanism capable of starting downbursts.

Early findings also indicate that, although visual observations cannot detect which clouds are producing wind shears, Doppler radars can identify changes in wind speed and direction in real time on a very small scale. Scientists are discovering that microbursts occur often enough to pose very real danger to aircraft. Because of JAWS, data are now available for evaluation so that detection and warning systems can be developed for hazardous wind shears.

Great Lakes Snow Storms

Along the downwind shores of each of the five Great Lakes are narrow snowbelts where the annual snowfall is several times that occurring at corresponding upwind locations. These snowbelts, which have an enormous impact on local business and agriculture, give direct evidence of one way the Great Lakes influence weather patterns.

Lake-effect snow storms occur when very cold air flows across the relatively warm lakes. What determines the size, intensity, location, organization, and duration of individual storms is not well understood; learning more about this is the goal of an NSF-supported study on storms around Lake Michigan. By combining data from weather-research airplanes, research Doppler radars, and conventional weather-observing systems, Roscoe R. Braham, Jr. and his University of Chicago colleagues have shown that weather structures on several scales combine to form lake-effect snow storms. Scientists from the Universities of Illinois and Wyoming, NCAR, and



Microburst effects. This schematic shows the dramatic effect a microburst can have on an aircraft's flight path. The plane approaching a landing expects to follow a straight-line path, the glide slope, to the runway. But as the downdraft fans out, the plane first encounters a headwind, which forces its nose up, and then meets a strong tailwind, which forces the nose down. At low altitudes, such as when taking off or landing, the pilot cannot compensate for these extreme changes and the plane may crash. The JAWS project is investigating these microbursts.

the U.S. National Weather Service are assisting in this study.

Project scientists have found four different modes of storm organization. They are trying to discover what determines the mode on any given lake-snow day. The main factors seem to be air-lake temperature differences, wind direction and speed as a function of height, and thermal stability of the air upwind of the lake. These factors in turn depend on the large-scale weather patterns over the midwestern United States.

Wind-parallel bands occur but usually do not produce sustained heavy snows. Cross-wind bands, observed several times on radar, seem to be limited to overland areas and do not contribute very much to the regional snowfall.

The midlake bands and shoreline bands can be much larger; they are also much more important in causing sustained heavy snow over the lake and the downwind shore. These two types of lake-effect storms are large enough to set up their own internal circulations, with low-level inflow and convergence beneath the line of clouds and outflow aloft. Often one finds wind-parallel snow bands over the lake feeding into a shoreline band along the downwind shore.

The midlake snow bands over Lake Michigan seem to have several features in common with the major snow bands of Lakes Erie and Ontario. However, the great differences in size and orientation of the upper lakes (Superior and Michigan) compared with the lower lakes (Erie and Ontario) result in many differences in the frequencies and structures of their snow bands.

Along with more knowledge about lake-effect snow storms, practical benefits expected from this type of research include better predictions of winter snow storms, more accurate assessments of the role of lake-induced storms in regional water supplies, and perhaps a better understanding of how the Great Lakes contribute to winter weather in the northeast.

Effects of Vulcanism on the Atmosphere

Recent spectacular volcanic eruptions have heightened interest in the effect of vulcanism on the atmosphere. Volcanic eruptions markedly augment the concentration of airborne particles (aerosols), which may have global cooling effects lasting up to several years. Most of these climatic effects are believed to result from submicron particles of sulfuric acid formed from sulfur gases emitted by volcanoes.

The only way to study short- and long-term variations in the aerosol layer is to have a long series of measurements. David J. Hofmann and James M. Rosen, of the University of Wyoming, have made balloon soundings of the aerosol layer over Laramie since 1971. The series of measurements has recorded aerosol levels after several volcanic eruptions and during the intervening periods when particle counts declined.

In the spring of 1982, El Chichon erupted in Mexico. This has been called the biggest geophysical event of the century in terms of potential climatic impact. Three months later the El Chichon plume was observed over Laramie at 22 to 25 kilometers altitude. The basic research project there made it possible to observe the early stages in the evolution of both the Mount St. Helens and El Chichon plumes. For the latter, balloon soundings made *in situ* observations unobtainable by any other means. The high concentrations of sulfuric acid in the El Chichon plume suggest that this volcano may have a noticeable climatic effect, in contrast with the Mount St. Helens eruption.

The Wyoming project, which has yielded the longest record of *in situ* stratospheric aerosol observations at a single location, provides fundamental data in developing models of stratospheric aerosols and their effects on global climate. Included are data on aerosol chemistry, particle growth rates, the latitudinal spread and decay rates of plumes, and background levels relatively unperturbed by volcanic activity.

First supported solely by another federal agency, the Wyoming effort came under NSF sponsorship in 1976. Partial, though lesser, support since that time has come from three other federal agencies.

NCAR researchers also have measured the impact of volcanic eruptions on concentrations of various chemical compounds in the stratosphere for several years. Their measurements and those of the University of Wyoming scientists should begin to define more clearly the effects of vulcanism on the atmosphere.

Western U.S. Water Supply

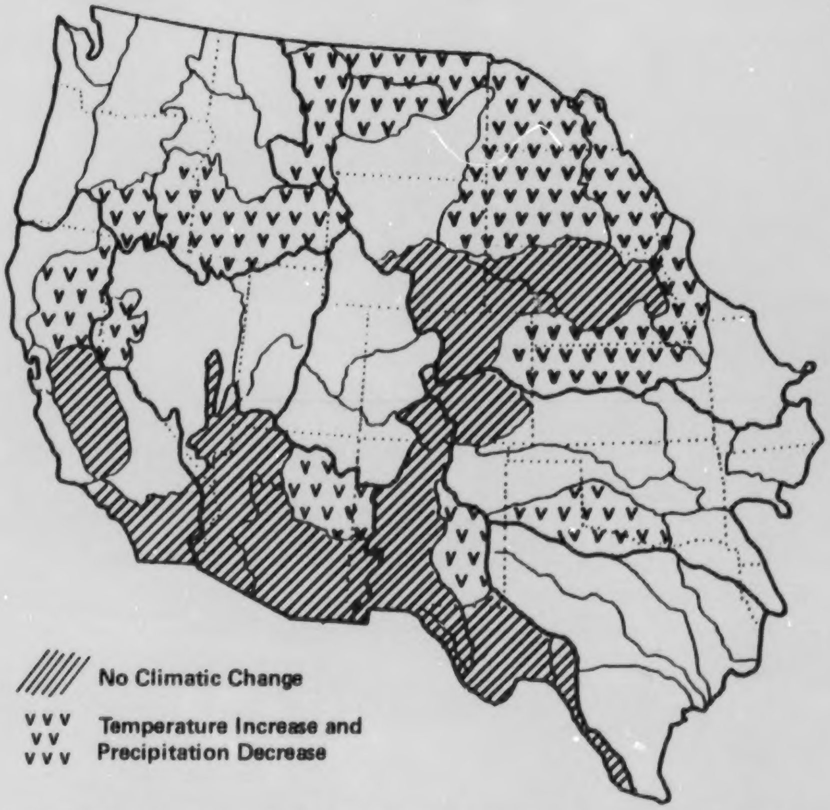
The steady shift of U.S. population westward has intensified regional water supply problems. Two University of Arizona scientists have shown that the early part of the 20th century, when major water rights for the Colorado River Basin were established, was an abnormally drought-free period. Now the growing demand for water from this basin and the possibility of long-term warmer and drier conditions in the area both pose the possibility of severe regional water crises in drought years.

Charles W. Stockton and David M. Meko, of the University of Arizona's Laboratory of Tree Ring Research, have reconstructed the history of drought conditions in the western United States and found severe, recurring droughts during the last 400 years. They created the climatic record from the variable width of tree rings in the earlier years, coupled with precipitation and river-runoff data for about the last 100 years.

Stockton and Meko have developed a water-balance model to identify certain areas in the region where a climatic change would cause water shortages or damage habitats for aquatic life. They considered two climatic changes: (1) an increase in mean annual temperature of 2 degrees centigrade, and (2) that temperature increase combined with a decrease in annual precipitation of 10 percent.

The water-balance model yielded an average 10 percent decrease in regional natural streamflow for the first condition and an average 30 percent decrease for the second. These results assume that the amount of mined ground water remains unchanged from today. Since several of the groundwater aquifers are suffering long-term depletion, the actual water availability in the region is likely to be reduced even more than those figures indicate. Also, it is clear that if there is a reduction in the mean streamflow of as little as 10 percent in the next century, the effect of two or three severe drought years back to back will be devastating. The reconstructed climatic record shows that such extended droughts in the Colorado River Basin have happened seven times in the last 400 years.

Stockton and Meko are improving their model and extending the tree-ring reconstructions back in time and over wider sections of the United States. Their work on this critical topic has importance far beyond its scientific significance. In addition to their efforts, researchers at NCAR, as well as others supported by NSF grants, are doing studies on the effects of drought and water supply.



Possible drought. In the year 2000, and assuming the current rate of groundwater mining, some parts of the western United States are projected to have inadequate streamflow (the flow of water out of an area in an average year). Two scenarios are shown here: (1) unchanged climate and (2) an increase of 2 degrees centigrade in mean annual temperature combined with a 10 percent decrease in yearly precipitation. White areas are projected to have adequate streamflow in 2000 for both scenarios. These predictions come from research on tree rings that reveal the history of droughts. The work may help planners prevent devastating dry spells in the future.

Earth Sciences

In the United States and in several European countries, the earth sciences are burgeoning in a number of ways. These include the application of plate tectonics theory to the structure and evolution of the continental crust, more understanding about earthquake processes, and more knowledge on the formation of mineral deposits. University enrollments are at an all-time high because of the excitement generated by this science and the clear applicability of geological research to problems of society.

The Foundation supports fundamental research in the earth sciences through grants. To encourage interdisciplinary research and to ensure that there are no gaps in areas covered, NSF has structured its support around the following topics:

- Stratigraphy and paleontology—Research on sedimentary rocks and fossils, the framework for interpreting past conditions and processes on the earth's surface.
- Environmental geosciences—Study of the physical and chemical processes that occur at or near the earth's surface.
- Seismology and deep-earth structure—Observational, laboratory, and theo-

retical studies directed at a thorough understanding of the earthquake process, how seismic waves propagate in the earth, and the determination of earth structure from seismic observations.

- Experimental and theoretical geophysics—Research concerned with the physical properties of the solid earth. This includes the earth's dimensions; its magnetic, electrical, and gravitational fields; its dynamic processes; and the physical behavior of materials under the temperature and pressure conditions of the earth's interior.
- Petrogenesis and mineral resources—Projects that integrate field, laboratory, and experimental data to learn what happens in the formation of crustal rocks and minerals. Emphasis is on the formation of ore deposits.
- Mantle geochemistry—Studies of the geochemical origin and evolution of the earth, especially the mantle. Projects use chemical analyses of meteorites and samples of mantle rocks; these offer evidence of the earth's early composition and later modification.
- Experimental and theoretical geochemistry—Activities aimed at a rigorous and quantitative understanding of the chemical behavior of natural materials under the temperature and pressure conditions encountered within the earth.

Continental Margin Tectonics of the United States

The eastern and western margins of the North American continent contrast markedly in tectonic activity at present. Earthquakes, volcanic eruptions, and geothermal activity occur more frequently on the western seaboard than on the eastern, which is tectonically quiet for the most part. Such was not the case in the geologic past, however, and modern tectonic analysis suggests that the present difference is only transitory.

During the Ordovician period (approximately 450 million years ago), the eastern seacoast experienced active volcanoes, faulting, and magmatic intrusion related to a collision beween the North American continent and a land mass to the east. This tectonism is comparable to that now seen along the western margin of the U.S. After the Ordovician activity, a collision occurred between the eastern margin and parts of Africa, South America, and Europe—an event much like the present collision between Asia and its Indian subcontinent. Indeed, the ancestral Appalachian Mountains at that time probably exceeded 14,000 feet, and the mountain-building process was undoubtedly accompanied by large earthquakes similar to those that have devastated parts of China.

Major tectonic events change the shape of continental margins. NSF-supported research, using a combination of geologic, paleomagnetic, and geophysical methods, has documented some of these extraordinary events. Scientists working in the Pacific Northwest have discovered large areas (some of them the size of states) that seem to have originated south of the equator and only arrived in their present position less than 200 million years ago.

Similar "displaced terrains" have been documented in Maine and Massachusetts and appear to have formerly belonged to Florida, or to a land mass to the south. It is probable that a fault system, similar to that of the San Andreas, was responsible for the northward movement of these terrains. During the Appalachian Mountain building event, pieces of Europe and Africa also became permanently fixed to the eastern seaboard.

The discovery of displaced terrains improves our understanding of the complex structure of continental margins and has important implications for future discoveries of both fuel and nonfuel mineral resources.

Mineral Resources

The depletion of near-surface ore reserves, particularly those involving strategic minerals, points to the need for more understanding of how ore deposits form deep in the crust. We also need to know how the location of ore deposits is related to regional structure and tectonic setting.

A multidisciplinary approach has proved fruitful in several research projects. For example, geophysicists, petrologists, geochemists, and paleontologists combined their talents in the U.S.-Japan-Canada cooperative research on the genesis of volcanogenic massive sulfide deposits. Their work added to our understanding about the formation of massive sulfide deposits, which are sources of lead, zinc, copper, cobalt, cadmium, antimony, silver, gold, and arsenic.

Mineral resources. Photo shows a fluid inclusion from the Panasqueira, Portugal tin-tungsten deposit, the leading source of tungsten in western Europe. The presence of certain liquids and gases in iron ores gives scientists key information about the formation and history of postmagmatic hydrothermal ore deposits. The field of mineral resources is a key research focus for the 1980s—and a good example of the way basic research directly influences exploration.

These deposits often occur in an environment of crustal extension or rifting. During the formation of a rift, where the flow of heat into the crust is high, the kind of vigorous hydrothermal circulation required to form massive sulfides occurs. Failed rifts—those that do not become oceans—have great potential for exploration.

One of the most important outcomes of the U.S.-Japan-Canada project on the Kuroko massive sulfide deposits in Japan is a hypothesis that relates these deposits to others whose origins were not well understood before. For example:

- Kuroko-type deposits (typically enriched in copper, zinc, lead, and sulfur) may result if the rift is in an island arc that formed since early Precambrian times.
- Archaen or primitive greenstone belts (typically enriched in nickel, copper, cobalt, and gold) may occur if the rift formed before the earth developed an oxygen-rich atmosphere.
- "Cyprus" type massive sulfide deposits (typically enriched in zinc, lead, cadmium, copper, gold, and silver) probably result from a rifting event that involves a midocean ridge cr mature marginal basin.
- Sediment-hosted deposits (typically enriched in lead, zinc, and sulfur) may form if the rift is within a continent.

Studying the Earth's Interior with Synchrotron Radiation

Synchrotrons are particle accelerators originally designed for experiments in high-energy physics. Earth scientists have now begun to use synchrotron radiation in experimental studies looking at the structure and composition of materials representative of the earth's interior. Our understanding of that interior depends on what we know about how materials behave under the extreme pressure and temperature conditions deep within the earth.

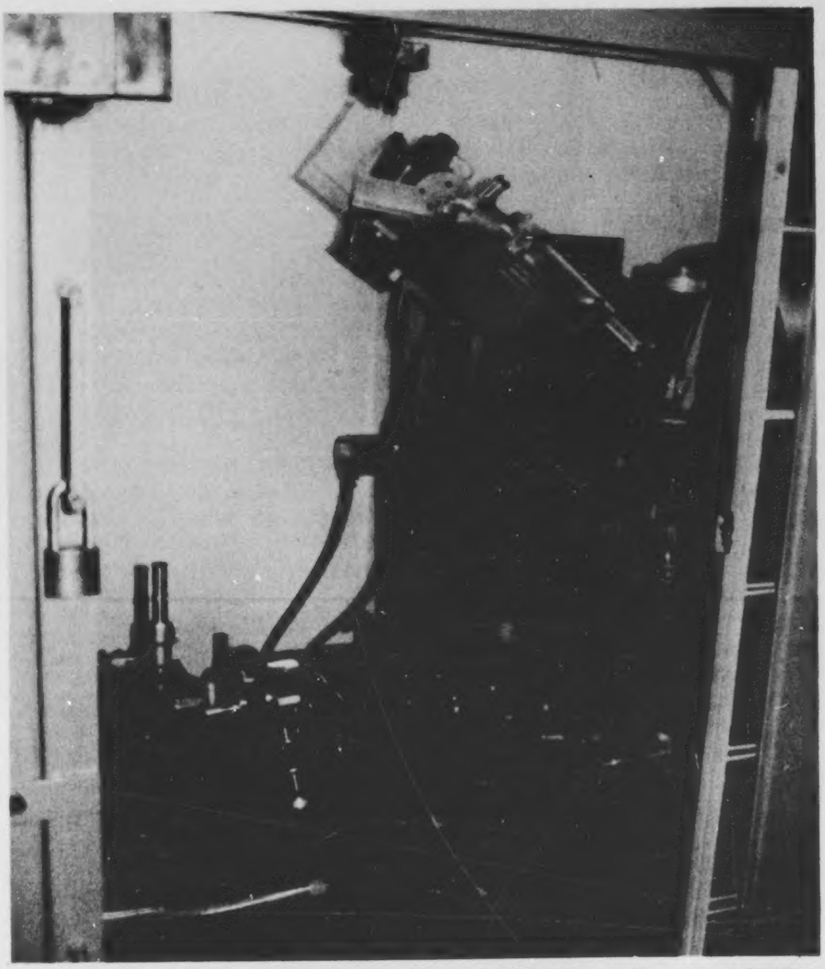
Development of the diamond-anvil, high-pressure cell, in which samples are squeezed between the faces of two diamonds, permits experimental investigation of the way materials behave at static pressures up to 20 million pounds per square inch—equivalent to the pressure encountered at the edge of the earth's core. The diamond anvils also serve as windows for direct observation and characterization of the sample under pressure.

Characterization of crystal structures by x-ray diffraction through the diamond windows gives quantitative information on compressibilities, equations-of-state, and phase changes, including chemical decomposition into simpler compounds. But such studies have been severely limited by the microscopic sample size, the scattering and absorption of x-rays by the diamond anvils, and the restricted geometry of the high-pressure cell.

These problems are being overcome by the availability of intense x-ray beams from synchrotron radiation sources. As electrons for positrons travel around the closed-circuit path of the accelerator or storage ring, they emit electromagnetic radiation; its energy (typically x-ray or ultraviolet) depends upon that of the particles plus the bending radius in the ring. This radiation, an unavoidable by-product of high-energy physics experiments, is now being applied in other branches of science and has been described in *Business Week* as the "most powerful tool since the microscope."

Experimental geochemists and geophysicists are using facilities at the Stanford Synchrotron Radiation Laboratory and the Cornell High-Energy Synchrotron Source, which can provide x-ray beams a million times as intense as those from conventional x-ray sources. These ultrabright beams permit very short exposure times; thus they add to both the quantity and quality of data. The beams also allow time-resolved studies of (1) the kinetics and mechanisms of phase transformations and (2) the rate of strain relaxation (and therefore the flow properties of materials) at very high pressures.

Adaptation to a synchrotron source has



Stanford Synchrotron Lab. This apparatus for x-ray diffraction studies—set up inside a "hutch" or radiation shield—is part of the elaborate instrumentation needed for experiments using synchrotron radiation. Earth scientists are now using this form of radiation in studies that look at the structure and composition of materials representative of the earth's interior. Some observers call synchrotron radiation an advance as important as development of the microscope.

required design modifications of the diamond-anvil cell. The lethal radiation levels involved require remote control of all adjustments, including the precise alignment of the cell to the x-ray beam (to within a thousandth of an inch). Such changes have been made, along with precise measurements of the compressibility and thermal expansion of several simple substances. These materials—including sodium chloride and gold—may be used as internal standards for pressure calibration in future experiments.

The successes of these technological innovations and of the early experiments have opened new regions for research in high-pressure geochemistry and geophysics and promise rapid advances in these fields.

Ocean Sciences

Techniques developed in many disciplines enable scientists to expand our knowledge of the ocean, the sea floor, and oceanic processes. Researchers in this field use broad, multidisciplinary efforts and modern technology to improve our understanding of the structure, genesis, and dynamic evolution of the continental and oceanic crusts.

Since the beginning of modern ocean science in the *Challenger* expedition a century ago, large projects and expeditions have played a key role in ocean research. The field developed especially rapidly in the United States during the International Decade of Ocean Exploration (IDOE) of the 1970s. IDOE brought new money into the field and new ways of organizing large-scale work, much of it international in scope. Several IDOE projects continued in 1982.

Since IDOE ended, NSF has begun 13 new large-scale projects at this writing. Most of the new efforts are quite broad, covering several areas of ocean sciences. An example is the Warm Core Rings investigation, which deals with the effects of huge warm-water rings on organisms in the slope waters of the western North Atlantic.

These rings, spawned by the Gulf Stream, are from 100 to 200 miles across. Studying them requires several cruises each year by two or three ships to sample rings located and tracked by satellites and aircraft. Satellite maps of sea-surface temperature are processed by computers and sent within one or two days to the ships to guide their sampling activities.

There was some concern that the large, interdisciplinary projects begun during the IDOE would adversely affect later funding for small efforts. But small projects continue to be the backbone of ocean sciences research.

Basically a field-oriented science, oceanography's progress depends on the ability of scientists to observe, measure, and sample ocean phenomena directly. They do most of their work on research vessels on the high seas, far from the convenience of shore laboratories. Those vessels must be able to support a variety of research missions.

As the primary source of support for U.S. academic oceanography, the Foundation has assumed responsibility to ensure adequate research facilities for NSF-sponsored marine scientists. Since modern ocean sampling, measurements, and analyses place demands on research vessels considerably different from those 10 years ago, NSF continues to support ship upgrading, oceanographic equipment, and instrumentation.

In 1982 continued exploration of the East Pacific Rise on the Pacific Ocean floor added to our understanding of crustal-formation processes. Peter Lonsdale of the Scripps Institution of Oceanography, University of California, and Berndt Simoneit of Oregon State University reported in *Nature* magazine the results of dives by the deep-submersible *Alvin* in the Gulf of California. Those dives revealed a covering of thick deposits of rich organic sediments. In conjunction with the Office of Naval Research and the National Oceanic and Atmospheric Administration, NSF is making preliminary plans at this writing to convert or lease an existing ship as a new tender for *Alvin*. This will give U.S. scientists access to more distant and remote geographic areas of high scientific interest. It will also mean a better capacity to accommodate new instruments and experiments for work on the deep-ocean floor.

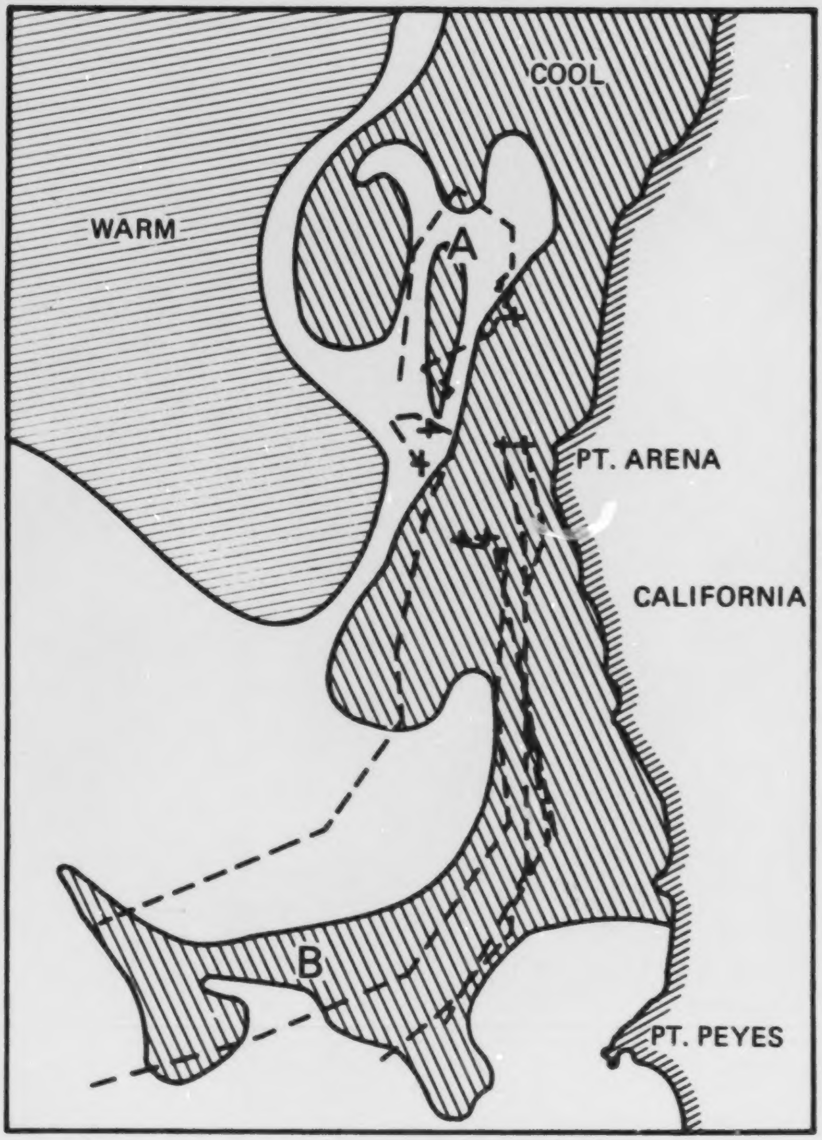
Coastal Ocean Dynamics

The results of recent field experiments show that the primary forcing mechanism for subtidal motion on most continental shelves is wind stress. The friction of wind on surface water, combined with the effects of the earth's rotation, can cause some of the surface layer to move away from the shore. It is replaced by an "upwelling" from below the surface. The upwelled liquid is cooler than the original water, and a characteristic band of coastal low temperature develops. Often upwelled water has greater concentrations of nutrients than the original surface water, which has been depleted by biological demands. Thus upwelling replenishes surface-layer nutrients essential for high biological productivity in the coastal zone.

Recognition of the importance of wind-driven coastal currents to the entire ecology of the continental shelf led to a four-year research program that began in 1980. Investigators from Oregon State University, NCAR, NOAA, the U.S. Geological Survey, the University of New Hampshire, Scripps Institution of Oceanography, and Woods Hole Oceanographic Institution seek to determine the key dynamic processes that govern wind-driven motion over the continental shelf of northern California. Their project is called the Coastal Ocean Dynamics Experiment (CODE).

Satellite images of sea-surface temperature have indicated that coastal circulation patterns vary greatly. Alongshore currents are often interrupted by plumes of cool water, which apparently run off the shelf; they are not permanent features but tend to recur at specific sites. At times they are formed quite rapidly by a "squirt" of water moving offshore. These squirts apparently come from the convergence of flow over the continental shelf in response to wind variations along the shore. The offshore flows are in turn typically rich in eddy signatures (reminiscent of cream stirred in coffee). CODE scientists have related these plumes and eddy features to strong velocity variability observed from ships and surface drifting buoys. Other features seen by CODE researchers include a strong "jet" of cool water directed straight offshore from Point Arena, California. Velocities of 40 centimeters per second were sustained for two days, and a thermal front was directed offshore and lasted for several days.

These offshore currents are important



CODE work. The Coastal Ocean Dynamics Experiment is looking into forces that direct wind-driven currents over the continental shelf of northern California. Satellite images show that coastal circulation patterns vary greatly, as seen in this schematic of an infrared image with superimposed surface drifter tracks (+ indicates launch point). Of special interest: the presence of an eddy (A) and a broad offshore plume of cool water (B). CODE researchers are learning much about the entire ecology of the continental shelf.

to the upwelling system. By looking at the relationships of these features to variability of the wind field, CODE investigators are testing different ideas on shelf dynamics and gaining new insight into the physical phenomena of the upwelling system. At this writing they have begun to develop new models for wind-driven coastal circulation.

Hydrothermal Vent Biology at 21 Degrees North

More than a hundred years ago, the *Challenger* expedition concluded that rich life dwelt in the cold, dark sea depth. Later research indicated that, although deep-sea organisms have a high species diversity, they grow slowly and are sparsely distributed because of limited food supply.

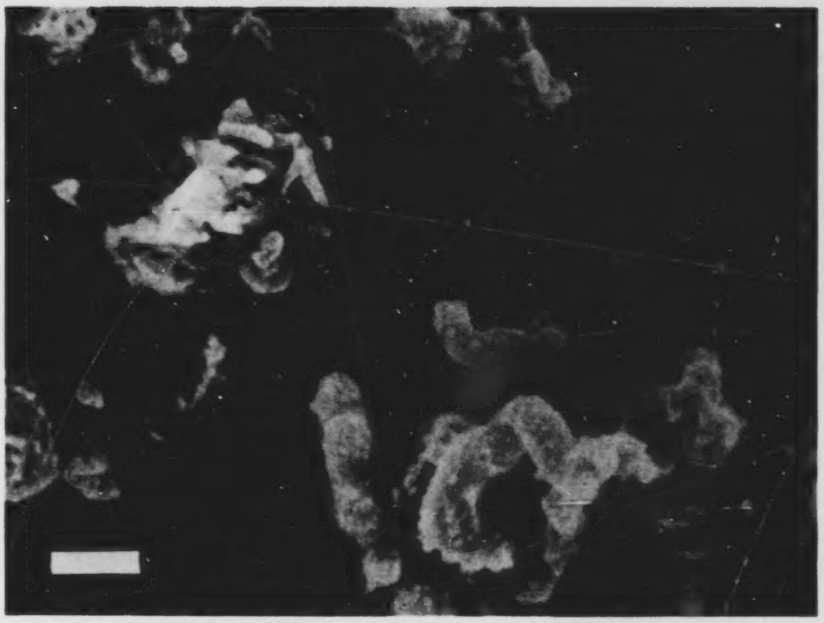
The mid-1970s marked the discovery of deep-sea hydrothermal vent communities, associated with submarine spreading centers. Biological studies at the Galapagos Rift vent reveal that organisms associated with the vent, including many remarkable new species, grow rapidly and are not limited to food supplied from the surface. In most food webs the primary producers are green plants that require sunlight for photosynthesis. By contrast, the primary producers in the vent food web are chemosynthetic bacteria that obtain their energy from inorganic sulfides coming from the vents.

The OASIS expedition, organized by Ken Smith of Scripps Institution of Oceanography and involving scientists from 20 institutions, visited a vent system off western Mexico in spring 1982. Here John Baross of Oregon State University made the startling discovery that bacteria exist in superheated plume water coming from black smokers.

At the hydrostatic pressures of the vents, water remains in the liquid phase up to 460 degrees centigrade. In the laboratory, under hydrostatic pressure and temperature simulating the vent environment, these bacteria can grow in a strictly inorganic medium containing thiosulfite, manganese, and iron as energy sources. Under these conditions they can double in less than 40 minutes. By contrast, the bacteria barely survive at "low" temperatures of 80 degrees centigrade.

The discovery that these vent organisms produce considerable methane, carbon monoxide, and hydrogen gas challenges accepted views as to how those gases are produced. The ability to precipitate trace metals, including manganese and iron, suggests a bacterial role in the formation of polymetallic sulfide deposits. Holger Jannasch of Woods Hole Oceanographic Institution and his colleagues have isolated more than 65 additional strains of sulfur- and methane-oxidizing bacteria from animal and mineral surfaces in the cooler waters surrounding the vent.

James Childress of the University of California at Santa Barbara and George Somero of Scripps Institution of Oceanography measured high sulfide levels in the blood of *Riftia* (worm) and *Calyptogena* (clam). These organisms concentrate sulfide with a special binding protein that transports sulfide to bacteria living within



Vent colony. These bacteria, isolated from the superheated waters discharged from deep-ocean vents, derive all their energy for growth from the oxidation of inorganic compounds. Certain trace metals are precipitated as a side effect of these life-supporting chemical changes. Bacteria such as these may be very important in enriching ore deposits with valuable trace minerals.

the animal tissue. The bacteria release sulfide from the protein for use as an energy source. Hydrogen sulfide, which other living organisms eliminate as a poison, may be an important energy source for vent animals.

Fred Grassle of Woods Hole Oceanographic Institution and his colleagues are studying the biogeography of vent animals and their dispersal patterns, to discover how these organisms locate a new vent when an old one dies. The scientists' new view of life in the deep sea now includes the vents as a series of oases, rich in unique marine life, flourishing along the submarine spreading centers.

Ocean Trace-Element Chemistry

The oceans contain a vast array of chemical species, often at extremely small concentrations. Few areas of science have seen such remarkable progress as in the ability of chemical oceanographers to analyze and describe these trace constituents. True, sample contamination in the dirty environment of a ship at sea is a perpetual problem, particularly for metallic species. With appropriate care, however, scientists can detect nanomolar or picomolar levels of many trace metals—even the concentration of common lead in deep-ocean water of about five thousandths of one part per billion.

What mechanisms maintain such low concentrations in the world's largest aqueous solution over geologic time? The problem is not lack of supply over the millennia; instead it is ease of removal. From the pioneering work of Karl Turekian of Yale University, who drew attention to the particle rain in the ocean, we now know that the removal process is related to adsorption, or "scavenging," as dissolved species adhere to solid phases. Marine chemists are just beginning to reveal this phenomenon and the short oceanic-residence time for many chemical species. The rare-earth elements offer one such example.

Gerald Wasserburg and Donald Piepgras of the California Institute of Technology have measured the picomolar levels of the rare earths samarium (Sm) and neodymium (Nd) in oceanic samples. The abundance of the isotope ^{143}Nd in nature increases through geologic time, due to production from the slow radioactive decay of ^{147}Sm. Thus crustal rocks of different ages exhibit varying Sm/Nd ratios.

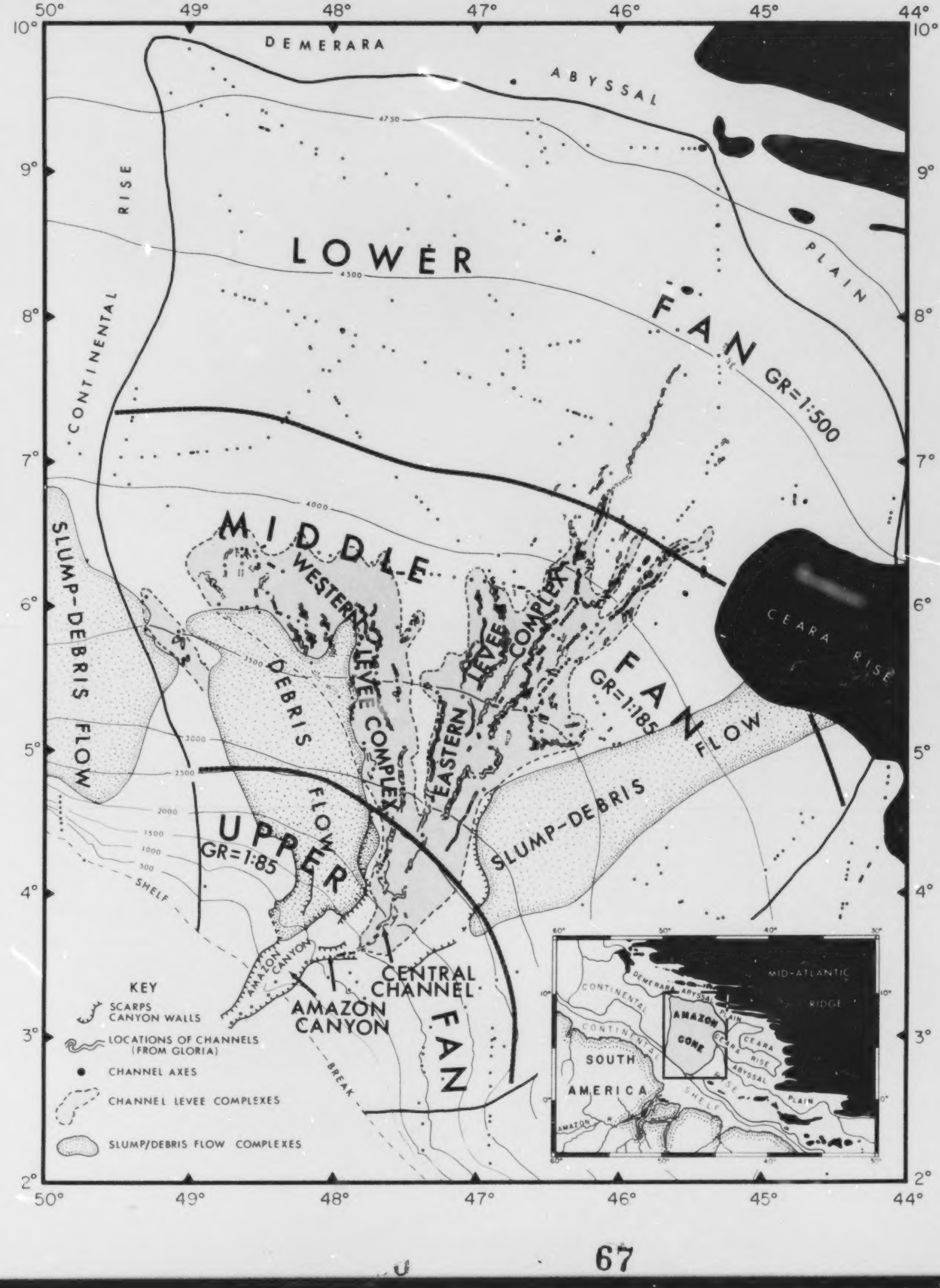
Samarium and neodymium readily hydrolyze in solution, show a marked tendency to adsorb on solid phases, and have oceanic residence times of only a few hundred years—short compared to the time scale of interocean mixing. The Pacific and Atlantic Oceans, therefore, maintain isotopically distinct Sm/Nd ratios; where these two oceans meet, in the Drake Passage, the proportions indicate that the Antarctic Circumpolar Current consists of about 70 percent Atlantic water.

For signals such as this to be fully interpreted, scientists need a more sophisticated view of the chemical processes controlling such short residence times. Michael Bacon of the Woods Hole Oceanographic Institution and Robert Anderson (now of the Lamont-Doherty Geological Observatory) have carefully investigated the removal of chemical elements onto sinking particles. Their results indicate a removal rate that is directly proportional to the dissolved/particulate fractionation of the metal and is driven by particles with a 5 to 10 year sinking time in the ocean water column. Sediment-trap experiments are giving a wealth of information on these particle fluxes and their chemical signals. Thus ocean trace-element chemistry is now undergoing a true revolution.

Meandering Channels on the Amazon Fan

An important problem in marine geology is deciphering the evolution of thick sequences of sediment that form adjacent to the continental margin. Such features, known as deep-sea fans, are often located off major river systems or continental-margin canyons. Since these fan sediments form a large share of continental-margin deposits, detailed knowledge of their sedimentary processes, growth patterns, and evolution is critical to understanding the entire margin, its history and origin. Additionally, deep-sea fans have become increasingly important targets for hydrocarbon exploration.

Because of the large area of most fans, conventional geologic surveying and mapping tools have given only a limited view of their morphology and sedimentary processes. Fans are composed dominantly of eroded continental sediments apparently transported to the deep sea by sporadic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LOWER
FAN
GR=1:500
MIDDLE
FAN
GR=1:185
WESTERN LEVEE COMPLEX
EASTERN LEVEE COMPLEX
DEBRIS FLOW
SLUMP-DEBRIS FLOW
SLUMP-DEBRIS FLOW
CEARA RISE
UPPER
GR=1:85
FAN
SHELF
BREAK
AMAZON CANYON
CENTRAL CHANNEL
AMAZON CANYON
KEY
SCARPS CANYON WALLS
LOCATIONS OF CHANNELS (FROM GLORIA)
CHANNEL AXES
CHANNEL LEVEE COMPLEXES
SLUMP/DEBRIS FLOW COMPLEXES
60°
50°
40°
30°
10°
0°
MID-ATLANTIC
RIDGE
DEMERARA
ABYSSAL
PLAIN
CONTINENTAL
CONTINENTAL
AMAZON
CONE
CEARA
CEARA
RISE
ABYSSAL
PLAIN
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SHELF
SOUTH
AMERICA
AMAZON
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turbidity flows. Such flows produce channel systems across the fan as they slow down and deposit their sediment load.

Although the existence of these channels on fans had been known for some time, recent research on the Amazon Cone (or Fan) off the northeastern coast of Brazil promises important new insights into channel and fan sedimentation processes.

Led by John Damuth, scientists at Lamont-Doherty Geological Observatory of Columbia University, collaborating with Brazilian scientists, used the GLORIA side-scan sonar system of the British Institute of Oceanographic Sciences to map the Amazon Cone morphology and channel system. This sonar device uses returned acoustic signals to provide data on sea-floor morphology—up to 15 kilometers on each side of the ship's track.

The most striking and surprising characteristic of the Amazon Cone channels revealed in the survey is their extensive and intricate meander patterns. Nearly all channels observed below 2,500 meters depth on the middle and lower fan showed high sinuosity and well-developed recurving meanders. Channels shallower than 2,500 meters also meander, but the sinuosity is lower and recurving meanders are not usually observed. The channels below 2,500 meters showed features and patterns that compare in morphology and size to flood-plain deposits and features of large river systems, such as the lower Mississippi.

These findings have important ramifications. The formation, maintenance, and modification of such meander systems would seem to require a fairly steady, high volume of flow through the channels for relatively long periods of time—a concept in striking contrast to the traditional one of channel formation by sporadic and intermittent turbidity currents. Further analyses of these data will try to relate the channel characteristics and morphology to possible hydrodynamic regimes and sedimentation patterns. Such work is essential to developing models for fan sedimentation and evolution.

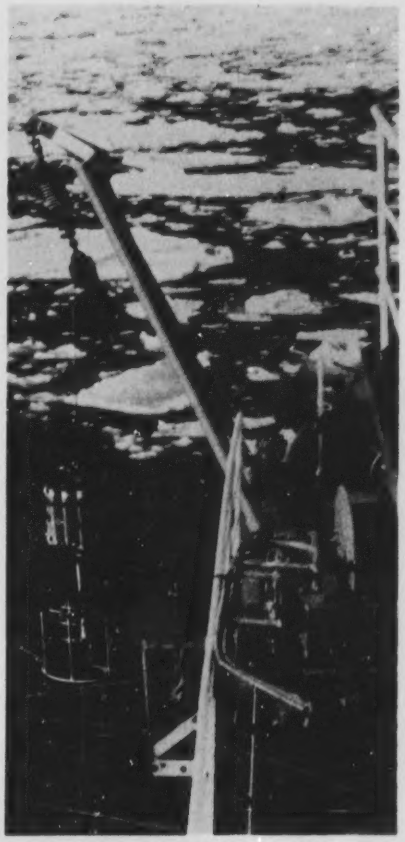
GLORIA scan. Scientists used the British sonar system called GLORIA to map the Amazon Cone, or Fan, and its channels. In this case, the western and eastern levees were under special scrutiny. GLORIA's acoustic signals give data on sea-floor structure; these data are critical to our understanding of the continental margin and to possible exploration for hydrocarbons.

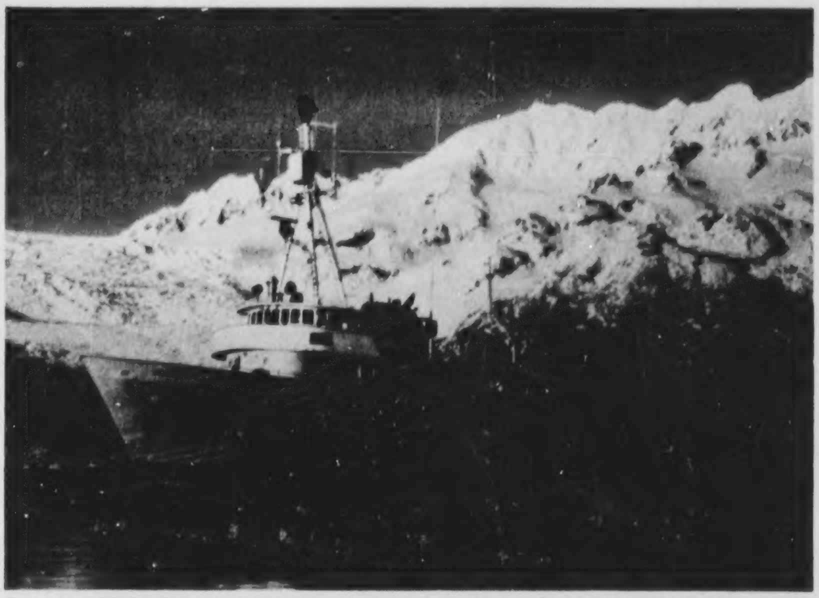
Oceanographic Facilities

In 1982, 151 scientific programs were conducted on ships of the academic research fleet, often referred to as UNOLS (University-National Oceanographic Laboratory System). The projects required nearly 3,100 days at sea, ranged from the Arctic Ocean to the Southern Ocean and from Japan to West Africa, and involved all major disciplines of the ocean sciences—marine geology and geophysics; physical, chemical, and biological oceanography; air-sea interaction; and ecology and environmental quality. Operating costs for the UNOLS fleet ranged from $500 a day for the smallest coastal vessels to more than $11,000 a day for the largest open-ocean ships.

There were no important changes in the size or composition of the fleet in 1982. General-purpose surface ships continue to be the primary requirement. NSF supports about 70 percent of operational costs; the Office of Naval Research (ONR), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey, and the Department of Energy fund the rest.

The research vessels (R/Vs) *Atlantis II* and *Columbus Iselin* underwent year-long





R/V Alpha Helix. This 41.5-meter vessel, part of the U.S. academic research fleet, was once a floating marine biology laboratory. Now converted, the general-purpose research ship can be used in icy seas (photo by Mike Miller). Above, a researcher lowers sampling instruments from the *Alpha Helix* into the eastern Bering Sea ice pack (photo by H. J. Niebauer).

maintenance and upgrading, which should significantly extend their years of service. R/V *Conrad* returned to service after its midlife refit and completed a full year of successful operation.

Plans to convert R/V *Atlantis II* for an *Alvin* support ship moved ahead. The deep-submersible vehicle *Alvin* is now supported by the catamaran *Lulu*, which lacks adequate accommodations, laboratory space, and, most important, sufficient endurance. During recent expeditions, an additional research vessel was required for accommodations or safety, increasing the cost of the *Alvin* program. With R/V *Atlantis II* as a support ship, scientists will have excellent laboratories, space for 16 scientists, and greatly improved range and endurance. NSF, ONR, and NOAA will continue to fund the *Alvin* program under an interagency agreement.

The year 1982 saw the final conversion of R/V *Alpha Helix* to an effective general-purpose research ship. The 41.5-meter vessel was designed and built as a sea-going marine biological laboratory. Transferred in 1980 from the Scripps Institution of Oceanography to the University of Alaska, the *Alpha Helix's* ice-strengthened bow, size, and configuration are well suited to the university's research activities. Modifications included the installation of a deep-sea winch, a bow thruster for precise maneuvering during scientific operations, and a deck crane for deploying and recovering instrument packages and other equipment. These and other changes have made the *Alpha Helix* effective for research projects in the Bering Sea and along the sea-ice margin. The modifications also gave the ship a lower center of gravity that enables it to operate in more diverse sea conditions.

NSF gave increased attention to scientific instrumentation in 1982. Along with emphasizing the new instrumentation to improve scientific capabilities and replace outmoded equipment, the Foundation began to stress the development of oceanographic instruments that have broad usage in the ocean sciences.

United States Antarctic Research

Antarctica is emerging as a critical issue on the international agenda. In 1961, 12 nations enacted the Antarctic Treaty, which reserves the region south of 60 degrees south latitude for peaceful purposes. Through the 1960s and 1970s, most of these nations operated stations and supported scientific research that produced substantial knowledge of the region's physical and biological makeup and its relationship to global systems. Among other achievements, antarctic research pointed to a potential for exploitable resources—particularly marine living resources and offshore oil and gas. During that period, the world's resource base was increasingly recognized as limited, and shortages developed in some areas.

Antarctica is now receiving added attention. In 1977 and 1981 two more nations established year-round research programs there and became parties to the Antarctic Treaty. Twelve additional nations have agreed formally to abide by the treaty but have not sent expeditions to Antarctica at this writing. Still others launch ship-based summer research expeditions, or they send observers to the stations already set up by other countries.

Meanwhile, the treaty nations have developed means to encourage the conservation and wise use of Antarctica's resources—a subject not addressed by the treaty itself. They have agreed on measures to conserve fauna and flora, seals, and marine living resources. Work on the most difficult issue—the exploration and exploitation of minerals—began in the mid-1970s and has not yet ended. This task is complicated by territorial claims asserted by seven nations but not recognized by others.

Within this context the United States, which has not made a territorial claim in Antarctica and does not recognize the others, has worked since 1957 to maintain an active and influential presence in Antarctica—one that responds to U.S. scientific, economic, and political objectives. At this writing, the U.S. Antarctic Research Program consists of a ship and four year-round research stations, annual deployment during the austral summer of about 300 investigators on some 85 research projects, and operation of the necessary logistics and support functions.

The research program is balanced among the disciplines of upper-atmosphere physics, meteorology, geology and geophysics, glaciology, oceanography, and biological and medical research. The National Science Foundation funds and manages the program, which includes logistics provided by two federal departments (Defense and Transportation) and by a private contractor. As in other Foundation programs, scientists are selected from universities and other institutions to do the research.

The President of the United States reaffirmed the U.S. program and policy for Antarctica in a memorandum of 5 February 1982. Recognizing that increased interest in the continent may require work in addition to the Foundation's program, he also directed that under certain conditions other agencies may be involved there in certain short-term scientific activities.

First Antarctic Land-Mammal Fossil

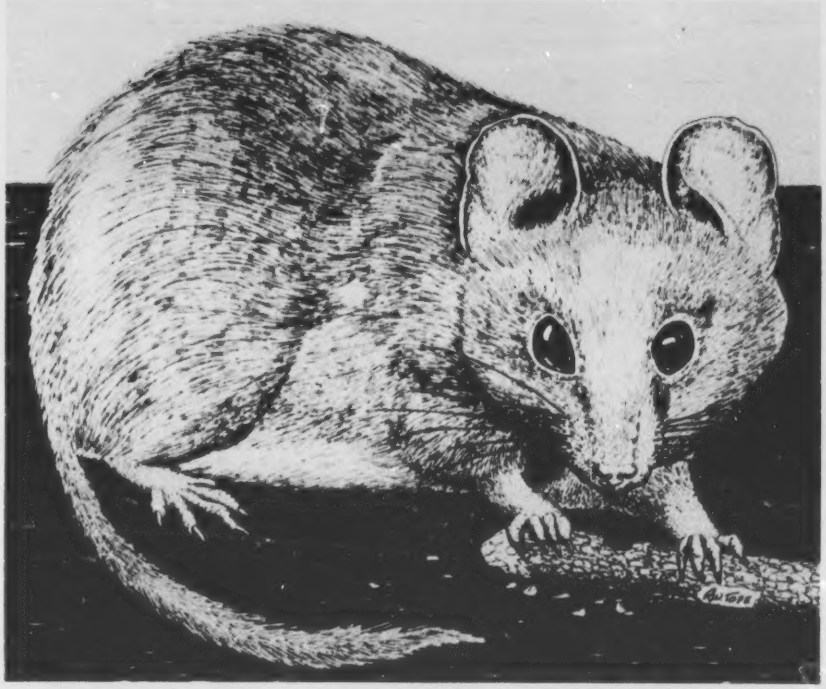
With an average annual temperature far below freezing and a land mass almost wholly obscured by an ice sheet up to three miles thick, Antarctica supports little life. Lichens and bacteria grow on some of the exposed rocks, but only two species of flowering plants and two wingless insects have been reported even in the relatively mild climate near the Antarctic Circle.

These present-day conditions belie Antarctica's warm past. And Antarctica's present isolation from the other continents belies its central position in the protocontinent Gondwanaland.

Fossil discoveries have contributed much to an understanding of Antarctica's paleoclimate and paleoposition. Early in this century Permian-age rocks bearing the fossil leaf *Glossopteris* were discovered in the Transantarctic Mountains. This rock type is matched in the other southern continents, suggesting that Antarctica was joined to one or more of them 270 million years ago. Just 13 years ago part of the upper jaw of *Lystrosaurus*, a dog-size four-legged reptile, was found—also in the Transantarctic Mountains. This reptile lived on the other southern continents too, and its presence in Antarctica is strong evidence that the continents were joined in the Triassic period, which began 230 million years ago.

On 5 March 1982, for the first time in Antarctica, U.S. paleontologists found a fossil land mammal. The animal was a small, rodentlike marsupial of the genus *Polydolops*. The remains were recovered on Seymour Island, near the tip of the Antarctic Peninsula. The fossil clearly suggests the presence of a former land connection (or a series of close islands separated by shallow water) between the peninsula and South America. This connection existed at some time between the late Paleocene (when polydolopidae first are known from South America) and the late Eocene (when they are now known from Antarctica), or 55 to 40 million years ago.

The fossil find confirms theories of past marsupial distribution, which predicted the presence of those animals in Antarctica and presumed that Antarctica was a land bridge between the Americas and Australia. These are the only continents on which marsupials have existed. The find suggests that the land connection between the Antarctic Peninsula and South America was



First fossil of an antarctic land mammal. The artist's conception (by R. W. Tope, Ohio State University) shows *Polydolops*, a fossil of which was found in early 1982 on Seymour Island, Antarctica. The animal was perhaps the size of a small wood rat and ate berries. Photo (courtesy of Ohio State University) is side view of a jaw fragment from the fossil. This remarkable find suggests that the land connection between the Antarctic Peninsula and South America 55 to 40 million years ago was even closer than scientists had thought.

closer or firmer than usually depicted in map reconstructions based on submarine (sea-floor spreading) data.

The marsupial was found during an expedition led by William Zinsmeister of Ohio State University and including scientists from three other institutions. According to Zinsmeister, Seymour Island has the Southern Hemisphere's best fossil record of the late Cretaceous and the early Tertiary—from 100 to 30 million years ago.

The expedition had many "firsts." In addition to the marsupial, the scientists made the first antarctic discovery of Tertiary reptiles (lizards), Cretaceous bony fishes (holosteans), and a Tertiary coal seam. Fossils of at least two Cretaceous plesiosaurs (marine reptiles) were found—one perhaps 12 meters long, the other up to twice as big. The first antarctic plesiosaur, found on nearby James Ross Island in the 1970s, was represented by fragments of limited diagnostic value.

Katabatic Winds

Automatic, unmanned stations in Antarctica supplement the continent's manned stations in collecting weather data. Since 1975 the United States has operated 20 of the unmanned units in addition to its four year-round manned stations. The devices measure air temperature and pressure, wind speed, and wind direction for a year without needing any service. On a frequent schedule, they transmit the data to polar-orbiting satellites for storage and retransmission to ground stations.

In Wilkes Land the automatic weather stations focus on katabatic, or gravity-driven downslope, winds. The katabatic winds are caused by cold air near the surface literally falling downslope from Antarctica's high central ice plateau to the coast. These gales are the continent's most persistent wind pattern, and they influence weather throughout the region. Katabatic winds often surpass hurricane speed; stations on the coast of Wilkes Land have experienced gusts of 200 miles per hour.

Since 1980, five U.S. and four French automatic weather stations have been deployed along a line between the coast of East Antarctica and Dome C, which is 10,760 feet high and 700 miles inland. Before this, according to Gerd Wendler of the University of Alaska, scientists had measurements of the katabatic winds either on the coast or inland but could not follow the winds' trajectory. The unmanned stations have given the first comprehensive data against which models can be tested or new ones developed. Wendler and his colleagues have been able to define katabatic flow more precisely than before, and they have incorporated into the existing models such dynamic processes as blowing snow, inertial effects, and variations of slope angle.

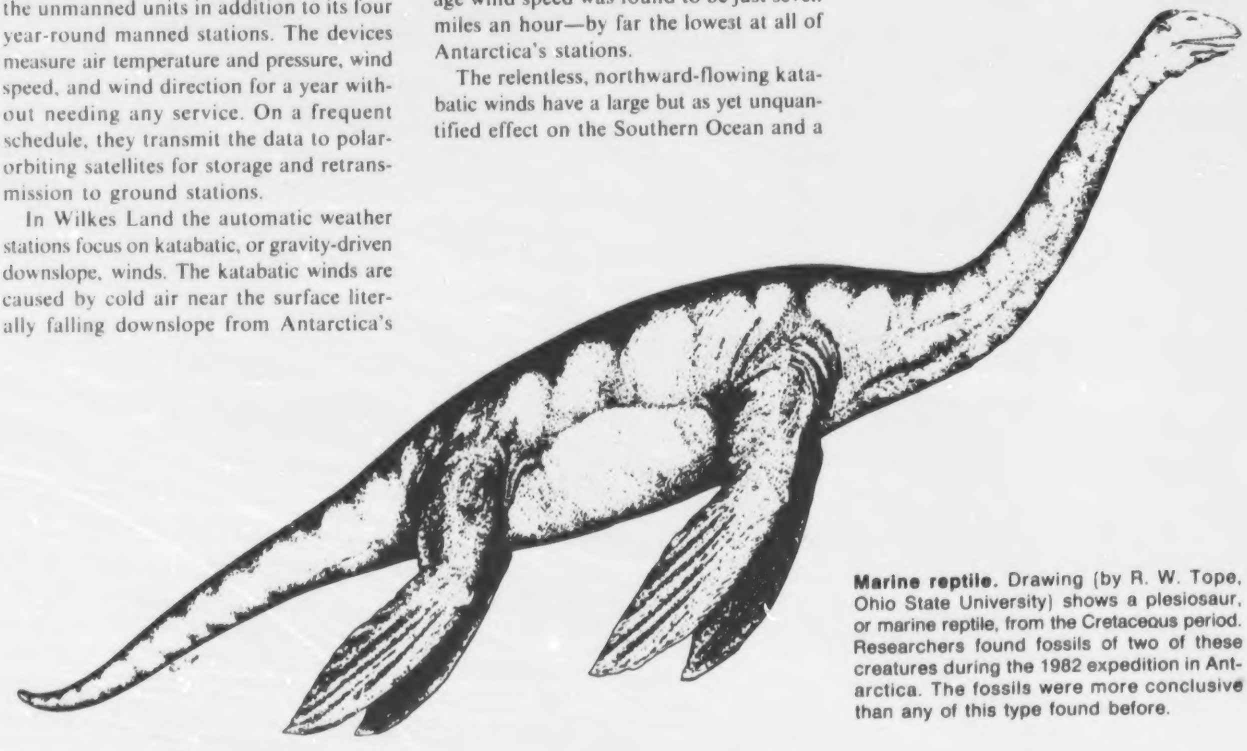
Dome C, at the inland end of the series of automatic stations, is the highest point in the area, and no katabatic wind should be occurring there. In fact, its annual average wind speed was found to be just seven miles an hour—by far the lowest at all of Antarctica's stations.

The relentless, northward-flowing katabatic winds have a large but as yet unquantified effect on the Southern Ocean and a profound effect on the atmosphere. The winds drive antarctic sea ice into the subpolar region; there the variable extent of ice on the sea is a sensitive climatic lever that can amplify the effects of small changes in global heating. The automatic weather stations provide the means to quantify the process where it starts—on the thousand-mile slopes of the east antarctic ice sheet.

Weddell Sea Oceanography

In October 1981 the Soviet research icebreaker *Mikhail Somov* entered Antarctica's winter belt of sea ice a thousand miles off Queen Maud Land. For the next two weeks the ship pushed southward through the ice. It reached a point 550 miles off the antarctic coast, then turned and headed for the open sea, which it reached on 14 November.

The voyage was remarkable for two reasons. It was the first ever to obtain a comprehensive, interdisciplinary set of data well within Antarctica's winter sea-ice cover. In addition, the research group had equal numbers of American and Soviet scientists.



Marine reptile. Drawing (by R. W. Tope, Ohio State University) shows a plesiosaur, or marine reptile, from the Cretaceous period. Researchers found fossils of two of these creatures during the 1982 expedition in Antarctica. The fossils were more conclusive than any of this type found before.

Arnold Gordon of the Lamont-Doherty Geological Observatory led the 13-person U.S. contingent; E. I. Sarukhanyan of the Arctic and Antarctic Research Institute, Leningrad, headed the Soviet expedition. The investigators were organized into teams to study physical oceanography, chemistry, biology, sea ice, meteorology, and the velocity of sound in the ocean.

The ship stopped 37 times for scientific work and also made observations en route. A special objective was to do measurements in a polynya—an open-water area within the ice—observed in satellite images in several prior years. Ice conditions were relatively heavy, however, and a polynya did not appear during the voyage.

The *Somov* work was done in an area defined as the Weddell Sea outflow of the Weddell Gyre. This gyre lies leeward of the Antarctic Peninsula between the antarctic continent and the eastward-flowing Antarctic Circumpolar Current. The gyre is a major producer of antarctic bottom water; cold and laden with nutrients, this water moves into the Northern Hemisphere to upwell at some locations and nourish fisheries.

While the *Somov* hydrographic data tend to confirm prior summer observations, they also have given new information on the movement of water masses in the region. One finding revealed intense eddies of relatively warm water, about 12 miles across, that rise to within about 130 meters of the surface. This upward movement can supply large amounts of heat to the atmosphere and probably contributes to formation of those polynyas that the expedition members had sought to study.

Zooplankton collections showed a dramatic difference in both biomass and numbers of individuals (or abundance) between the ice edge and the pack ice. Abundance under pack ice was 3 to 5 per cubic meter, while at the edge it was 25 to 42 per cubic meter. Because melting at the ice edge stabilizes the surface layers, abundance there exceeds that in the nearby open sea.

The expedition found wave heights greater than 0.25 meter that penetrated 120 nautical miles into the ice pack, twice the predicted distance. These waves are the remnants of long and high swells at the ice edge, a characteristic of the southern ocean and its high winds.

Arctic Research

Rapid development and environmental fragility in the American north have boosted interest in arctic research in recent years. Indeed, the region offers a unique opportunity to study many fundamental scientific questions.

NSF especially emphasizes arctic research on problems that require an interdisciplinary approach. Examples of Foundation-backed projects include these two:

- *Greenland Ice Sheet Program*, a study that emphasized measurement of surface features, bedrock topography, internal layering, and the drilling and investigation of ice cores.
- *Processes and Resources of the Bering Sea Shelf*, which investigated the causes of spectacular biological productivity in one of the world's main fishing areas.

In addition to these large interdisciplinary efforts, NSF supports arctic research within specific disciplines—geology and geophysics, biology, oceanography, glaciology, and the atmospheric sciences.

Nine other federal agencies also support or perform basic arctic research. Total federal support is some $85 million a year, with the Foundation providing about a fifth of that.

Arctic Heat Flux

The flux of heat into the arctic region is a crucial part of the global circulation system that determines the present climate and its long- and short-term variations. To understand the climate better, scientists must investigate the heat balance at high latitudes and the processes that maintain and modify it.

Both the atmosphere and the ocean carry heat northward at high latitudes, but seasonal changes in heat storage seem to be much greater in the ocean than in the atmosphere. In particular, the unique thermal structure of the Arctic Ocean is responsible for maintaining the ice cover there. It is important to learn whether there is potential for a change to vastly different conditions—an open, ice-free Arctic Ocean, for example.

The stable sea ice cover mainly determines the arctic climate. This cover reflects much more incoming solar radiation back into space than the open ocean does, so the amount of radiation absorbed depends upon how much ice there is. To know in which direction the amount of ice is changing, one needs to know how much heat is transported into the arctic, and how much stored heat may become available to melt the existing ice. Such circular effects can be either positive (by increasing the observed effect) or negative (by reducing the observed effect).

The Arctic Ocean has one principal opening to the Atlantic Ocean through the Norwegian and Greenland Seas. Earlier oceanic studies have shown an inflow of warm water in the Norwegian Atlantic Current (a northern branch of the Gulf Stream circulation) and an outflow of cold water along the east coast of Greenland. The East Greenland Current also exports an enormous amount of ice from the Arctic Ocean.

Fram Strait, the passage between Greenland and Spitsbergen, has been the focus of recent heat-exchange research. This work, sponsored by the Office of Naval Research and NSF, has shown a complex current system with energetic eddies existing on different space scales. The evidence for fluctuations in the water transport has placed a greater importance on concurrent measurements of outflow through the Canadian archipelago, and possibly through the Bering Strait.

Along with the growing numbers of direct, long-term measurements of the water and heat exchange through Fram Strait has come an increase in the number of oceanographic cruises to the Norwegian and Greenland Seas and the vicinity of Spitsbergen. In the summer of 1982, for example, the M/V *Lance* carried out a joint U.S.-Norwegian program for an integrated series of physical measurements in the Fram Strait area. The long-term deployment of pressure gauges will yield direct measurements of the total flow to complement data acquired during the cruise.

Scientific, Technological, and International Affairs

5

NSF's programs for scientific, technological, and international affairs (STIA) have unique functions that are central to the mission of the Foundation. Through activities supported by these programs, the work of NSF reaches many potential users across the United States—among them representatives of state and local governments, small business or industrial planners, academic scientists, groups of private citizens, and prominent decision makers in federal agencies, the Congress, and the Executive Office of the President. More broadly, these programs also link American scientists and engineers with colleagues doing research in foreign countries.

STIA programs include industrial science and technological innovation, intergovernmental and public-service science and technology, international cooperative scientific activities, policy research and analysis, and science resources studies. Their goals are as follows:

1. To conduct research programs that cut across disciplines and strengthen the scientific and technological (S&T) research enterprise, both nationally and internationally.

2. To collect and analyze data on the status of the national S&T enterprise.

3. To study public-policy issues in science and technology.

4. To serve NSF and other government decision makers who face complex problems pertaining to science and technology and the future of our country.

Industrial Science and Technological Innovation

Here the program goals are to:

1. Increase knowledge of science and engineering that is essential for technological innovation in the United States.

2. Link researchers with commercial users in the industrial sector.

3. Increase general understanding of innovation processes and how they are affected by government actions and private firms.

4. Evaluate institutional changes that are designed to influence overall technological innovation.

Innovation Processes Research

Intramural projects in this area include industry/university cooperative research centers, which have an important place in

Table 5
Scientific, Technological and International Affairs
Fiscal Year 1981 and 1982

(Dollars in Millions)

	Fiscal Year 1981		Fiscal Year 1982	
	Number of Awards	Amount	Number of Awards	Amount
Industrial Science and Technological Innovation	277	$ 17.06	210	$ 12.90
Intergovernmental and Public-Service Science and Technology	47	2.50**	38	1.20
International Cooperative Scientific Activities	282	10.07	363	11.58
Policy Research and Analysis	104	4.41	81	3.90
Science Resources Studies	46	3.10	41	3.14
Coordinated Agency-Wide Research Activities*	307	16.61	63	7.60
Total	**1,063**	**$53.75**	**796**	**$40.32**

*Formerly Cross-Directorate Programs

**Funds for Science for Citizens and for Ethics and Values in Science and Technology (totaling $3,065,691) came under the Science and Engineering Education appropriation in FY 1981

SOURCE: Fiscal Years 1983 and 1984 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

the national research effort. NSF staff, working with evaluators at the centers, have been assessing center operations and effectiveness—looking, for example, at scientific communication networks, organizational structure, and successes at each center. The group also wrote a manual on how to start and operate a cooperative research center.

In addition, NSF staff and scientists from several major universities analyzed social science contributions to technological innovation and national productivity. The paper resulting from their analysis also noted that possibilities for private-sector support of social science are limited.

Extramural projects include these:

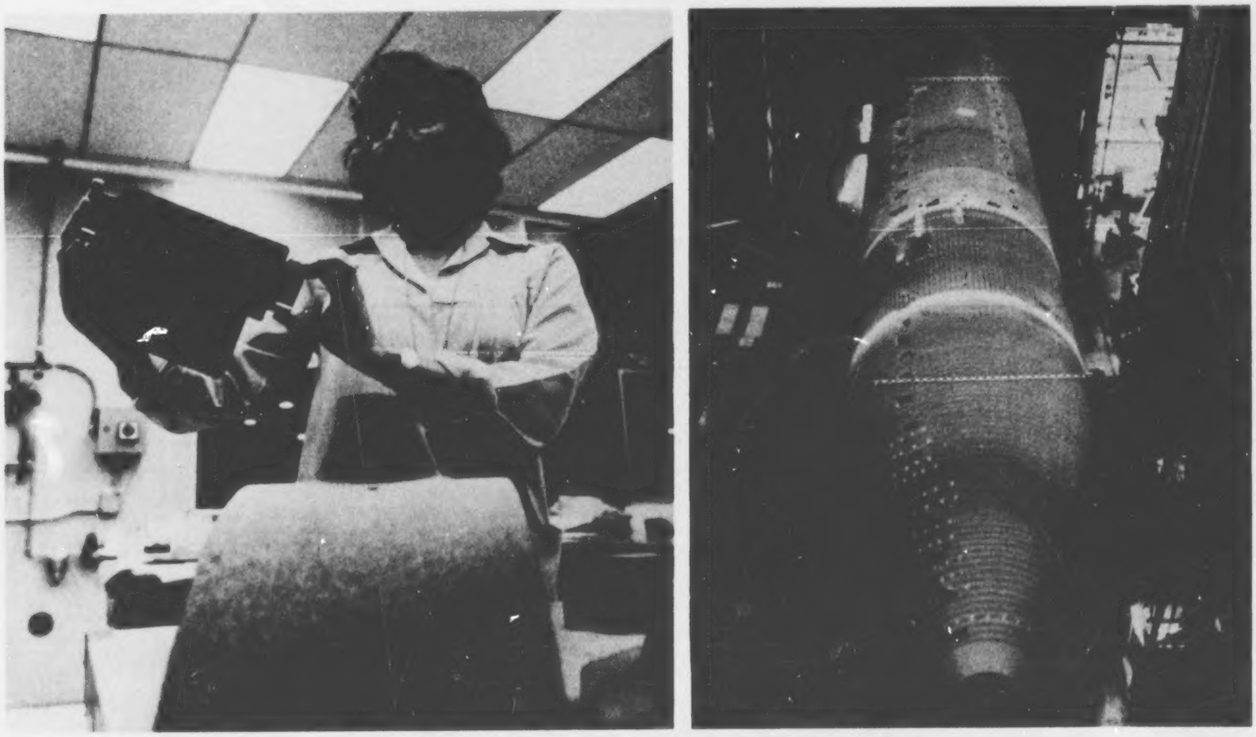
- The Rand Corporation, in an NSF-funded study, is examining social and organizational aspects of office automation and factors that may help or hinder it. The study has attracted considerable corporate attention, and several companies have been actively cooperating in the project.
- University of Michigan researchers are studying a national sample of firms with employee stock-ownership plans to learn how this growing form of organization affects worker motivation, productivity, and the pace of technological innovation.
- A project at California's University of Santa Clara looks at the venture-capital industry and the process and criteria used to make such investment decisions. The study includes interviews with both investors and high-technology entrepreneurs; it should give a rare view of "market failures" in this industry, along with data to guide future practices.

Industry/University Cooperative Research Projects

NSF sponsors cooperative research done by university and industrial scientists and engineers. Joint proposals, reviewed as is any other scientific proposal, are judged and awarded grants on the basis of the best arrangement for the cooperative research effort. Significant cost sharing is required of industrial participants.

Approximately 17 percent of these awards have gone to partnerships involving universities and small business firms. Projects funded as of this writing have been divided about equally between engineering and scientific fields. Chemical or electrical engineering, materials research, and chemistry have produced the largest number of proposals. Some examples of projects include:

- The Illinois Institute of Technology and Bell Laboratories are developing an infrared intracavity spectrometer to study chemical-vapor deposition reactions. This research will have practical applications in the manufacture of solid-state electronics, solar cells, and optical fibers for telecommunications. The advanced scientific instru-



Materials research and the space program. A Martin Marietta technician inspects the space shuttle *Columbia*'s external tank parts, which are covered with an ablative insulation material. Martin Marietta and the Massachusetts Institute of Technology developed a time- and cost-saving technique for applying the insulation. MIT's polymer processing effort began with an industry-university cooperative research grant from the National Science Foundation. (Second photo shows entire external fuel tank for *Columbia*'s rockets.)

mentation developed and used here offers an added technological bonus.

- To seek new energy- and cost-efficient materials for the packaging and container industry, a chemical engineering professor at the Polytechnic Institute of New York and scientists at Allied Fibers and Plastic Company are working with thermoplastic polymeric materials. Thermoplastics have been replacing glass and metal containers, doing the same job at lower cost and superior performance. With the use of two or more sandwiched layers of thermoplastics, strength and barrier protection will improve. The sandwiches are made by pressing out the polymers together.

  This project focuses on ways to avoid instability in the interfaces between the plastic layers. The information it produces will improve the theoretical basis for design and control of innovative industrial processes.

- A new type of chemical reactor—a membrane reactor—came from the research of a team at General Electric and the University of Pennsylvania. This new product allows a chemical reaction to occur with the help of catalysts, then separates and concentrates the reaction products. The reactor is expected to perform catalytic processes that require less energy and a smaller capital investment than other devices currently in use. Possible applications include the synthesis of a lead-free antiknock additive for gasoline and the production of an intermediate chemical product in semisynthetic penicillin manufacture. The university applied for a patent, and licenses are available to industry through university patents.

- Possible catalyst designs for an oxygen-reduction electrode were investigated by a research team of chemistry professors at Stanford University and the California Institute of Technology, along with a senior research scientist at the Hercules Company. This work involved two-electron transfer processes and the structuring of organic-metallic compounds for specific catalytic tasks. The team discovered a new oxygen-reduction catalyst, opening the way for other applications such as a hydrogen-oxygen fuel cell. New sources of electrical energy to heat buildings or fuel cars could result.

Intergovernmental and Public-Service Science and Technology

These programs, which reach important sectors of the nonscientific community, are intended to:

- Encourage the integration of scientific and technical resources into the activities of state and local governments.
- Identify, analyze, and help resolve the ethical and social dilemmas arising in and from the work of scientists and engineers.

The Foundation directed recent intergovernmental activities mainly toward those in state and local governments who use scientific and technical resources. Through NSF efforts regional and national networks, public-interest associations, and other resource groups are encouraged to (1) further government understanding of how to use scientific and technical resources, (2) offer information and technical services to governments, and (3) organize interjurisdictional information networks.

Information and technical services come through workshops, site visits, newsletters, and cooperative arrangements with the academic and private sectors to address common problems. Assessments of these activities yield important lessons and help identify future needs and strategies. Program efforts are designed to capitalize on NSF's experience, encourage the replication of previous successes, and help transfer support to nonfederal sources.

The Foundation also aids research and related activities that address the ethics and values involved in scientific and technical work. Issues of general concern are analyzed and the results widely disseminated. The National Endowment for the Humanities supports these efforts along with the Foundation.

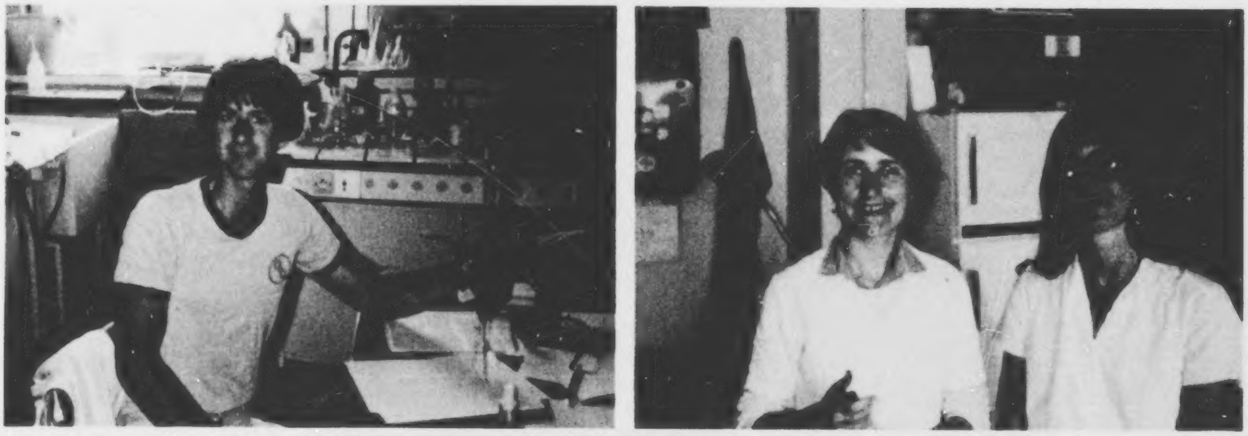
Some questions raised in recent projects on engineering ethics included these: Do engineers have special professional responsibilities? How should they deal with the risks associated with or stemming from the work they do? How can their organizational environments be structured to improve professional responsibility or help them manage risks better? Can professional societies and engineering educators play a special role in dealing with these problems?

These are not questions to which final, definitive answers can be given. However, projects can help identify problems and describe options and partial solutions. For instance, in an extensive survey of engineers employed by two organizations with a history of designing safe products, the vast majority reported that their concern for safety came from an organizational emphasis, not from their education or from professional societies. Managers in these companies were also positive about regulations as a source of protection from unscrupulous competitors and about public influence as a way of setting high product standards.

Engineers, social scientists, and philosophers also participated in a workshop to review the results of these studies and to devise strategies that promote safety in engineering design. (A volume that includes the two case studies and the workshop presentations is available from the Human Dimensions Center, Rensselaer Polytechnic Institute, Troy, New York.)

International Scientific Cooperative Activities

The Foundation manages some 30 cross-disciplinary programs with particular countries under bilateral agreements for cooperation in science and engineering. The costs for this collaboration are usually shared by the United States and the government of the participating country. Exceptions are India and Pakistan; for these programs



International exchange. Chemist Jonathan L. Sessler (left photo) received a U.S.-France exchange grant from NSF to work for a year on the chemical synthesis of a type of catalyst that may have wide commercial application in producing pharmaceuticals. Sessler was at the Louis Pasteur University in Strasbourg, France with Jean-Marie Lehn, who directs one of the world's leading research teams in this area of science. Also at Strasbourg on the same exchange program was chemist Cynthia Burrows (right photo, at right), shown with a French colleague at Lehn's laboratory. Burrows has a grant for 15 months to study the binding of organic ions to crown ethers. This topic is of great interest in organic chemistry and one on which Lehn's group has done much of the prior research.

the expenses of both sides are met by U.S.-owned special foreign currency held for such use.

NSF's bilateral partners in cooperative research fall into three groups: (1) the industrial, market-economy countries of western Europe, East Asia, and Oceania; (2) China and the centrally controlled, industrial countries of eastern Europe; and (3) the less industrial countries of Africa, Asia, and Latin America. One of these cooperative arrangements is described here.

Government participation aids the exchange of knowledge among industrial countries. For example, certain major research equipment and facilities have become so expensive that countries now agree to share their use and costs. Then too, formal binational arrangements often ease access by scientists from one country to the national laboratories of another. Moreover, encouraging strong personal ties among tomorrow's senior scientists is important to all countries; today's younger scientists find it difficult to spend substantial periods of time in research and study abroad without government encouragement and assistance.

Exchange of Scientists

The United States-France exchange of scientists grew out of a general framework for scientific cooperation established in 1960 as a symbol of improved relations. But there was also a mutual feeling that scientific cooperation between the two countries had lagged and needed bolstering. One feature of the agreement was a postdoctoral exchange of scientists. The two sponsors of the exchange—the French National Center for Scientific Research and the U.S. National Science Foundation—have effectively distributed information about the program and kept up a lively interest in scientific activity in both countries.

Exchange visits under the program usually last one year. Shorter visits are possible and beneficial to those familiar with the language and institutions of the host country. Typically, scientists in the program are under 35 years old and still in their formative years of professional development.

Each country selects applicants who merit support, based on the country's overall needs and perceptions of the host's research strength in specific fields, as well as general scientific merit. Awards under the U.S.-France exchange may be in the mathematical, physical, engineering, biological, and social sciences. More than 70 percent of French participants have chosen to work and study with U.S. chemists, physicists, and life scientists.

Policy Research and Analysis

The Foundation appraises the impact of research upon industrial development and the general welfare and is a source of information on policy formulation for other agencies of the federal government.

Areas of study include the contribution and impact of science and technology on the economy and society; patterns of international competitiveness, technology transfer, and monetary transactions; ways to assess and manage technological risks; and relationships among science and technology policies and those on environmental, energy, and mineral resources issues. Two examples follow.

Teletext and Videotext Systems

An NSF technology-assessment study examined some of the public-policy issues associated with the potential development of teletext and videotext in the United States. These are electronic systems for the widespread distribution of textual and graphic information. Display of the information relies on low-cost terminals under the selective control of operators who use procedures that nonexperts can easily understand.

Videotext is the generic name for systems that provide for two-way information flow, whereas teletext refers to one-way transmission services. This technology has the potential to change the way people use information.

The teletext/videotext public-policy debate—both nationally and internationally—has already begun. No single body of law or regulation has clear jurisdiction over this hybrid technology. Issues addressed in the technology-assessment study include the question of user access, the marketplace structure, the regulation of content, and the potential need for added copyright protection.

If and when widespread use of teletext and videotext becomes a reality, other issues must be examined. For example, what restrictions, if any, should there be on the vast amounts of personal information that could be collected from videotext systems? Defining an individual's right to privacy in this electronic environment is a complicated task but one of considerable public interest.

Videotext will also allow people to shop electronically. Here the policy issues include protecting consumers against questionable sales tactics and misrepresented products or services, as well as dealing with disputes and guaranteeing product quality.

Other issues include the question of antitrust legislation and the role of multinational corporations in what promises to be an international enterprise.

Taxation and Innovation

Several NSF policy studies have assessed relationships between taxation, innovation, and other variables, such as business confidence and market strategy. Their main question was: To what extent can (or do) tax measures stimulate industry to develop and use new technology? Associated policy questions are: Do other countries provide significantly better tax treatment of innovation than the United States does? Do specific tax incentives markedly affect innovation activities?

Over the last few years (1979-82), NSF directed a number of short-term projects to gather initial data and give interim assessments for use by the public-policy community until long-term statistical work could be completed. Results of this early work indicate that claims made in the public arena frequently overstate existing evidence about the use of innovation tax incentives abroad and the effectiveness of those incentives. Information and discussions stemming from these studies led to a definition of research hypotheses, stimulation of proposals, and funding of two long-term projects to assess tax effects on R&D.

One project will use statistical analysis to estimate effects of the 1981 tax act on R&D by year, industry, type of R&D, and type of firm. The second project will study the effects of tax variables on R&D for selected high-technology sectors in the United States, the United Kingdom, the Federal Republic of Germany, and Canada.

Science Resources Studies

Through this program, NSF does surveys and analyses of the nation's scientific and technical resources and publishes several series of reports and summaries. These publications go to a variety of users—including officials throughout the federal government, in state and local government, in educational institutions, and in industry—who develop science policy or allocate science resources. Analysts of the national and local resource-allocation system for science and technology make up another important audience.

During 1982, the Foundation continued to develop periodic and comprehensive national overviews of the S&T personnel situation and of past and current funding for S&T activities. Several reports of special significance are highlighted below.

The 13th annual report of the National Science Board, *Science Indicators—1980*, went from the President to the Congress late in 1981. The report is the fifth in a series providing indices of science and technology performance in the United States. The current volume contains more data than did previous reports in the series. It focuses on primary policy questions, offering alternative interpretations and pointing out limitations in the data. This volume also includes the results of a special comprehensive survey of public attitudes toward science and technology.

The third volume of a series, *National Patterns of Science and Technology Resources*, was also published during the year. This series provides a concise, current overview of U.S. science and technology resources. Data in the report indicate that total U.S. expenditures for research and development should increase in 1983 to $85 billion. R&D expenditures have increased in real constant dollar terms each year since 1975, averaging about 4 percent annually through 1983.

National R&D expenditures as a percentage of the gross national product have been going up slightly each year between 1977 and 1982. Over this period the national R&D/GNP ratio increased from 2.2 to 2.4 percent, compared with a peak of 3.0 percent in 1964. In 1983 the ratio is expected to remain at 2.4 percent.

Women and Minorities in Science and Engineering, published in the spring of 1982, responds to a congressional directive. This is a biennial statistical report on the participation of women and minority groups in technological jobs and training. The report highlights differences in job patterns between women and men and between whites and racial minorities. It also reviews a series of indicators, such as unemployment rates and salary differentials, to assess relative labor market conditions for scientists and engineers. Data are presented on the number and proportion of women and minorities earning degrees in science and engineering and on the ways that those groups acquire math and science skills before they enter college.

Among a number of special studies and analyses during the year was a report on the results of a special survey of small, high-technology companies engaged in research and development. The survey was supplemented by indepth interviews of a sample of the responding firms. A report, *Problems of Small, High-Technology Firms*, came out in the spring of 1982 summarizing the findings of both survey and interviews. The study documents and assesses the pervasiveness of certain problems among subgroups of high-technology firms.

Two-thirds of the firms identified these four areas as major concerns: providing competitive salaries and benefits, maintaining R&D work at adequate levels, dealing with nonprocurement regulations, and obtaining venture and/or working capital.

Scientific and Engineering Personnel and Education

6

In 1982 the Foundation focused on the most critical need—support to graduate students—while also fulfilling earlier commitments to ongoing projects. In addition, the National Science Board established the Commission on Precollege Education in Mathematics, Science, and Technology. The Commission began to examine the entire scope of U.S. elementary and secondary preparation in the technological fields. It also debated both the nature of the current situation and the most appropriate roles for federal, local, and private resources in finding solutions.

During 1982 all other science and engineering education programs at NSF were terminated, and the Directorate for Science and Engineering Education was restructured to form the Office of Scientific and Engineering Personnel and Education. The new office administers graduate fellowships, NATO postdoctoral fellowships, and continuing activities for awards made in previous years. It also offers information to the many public and private agencies working to improve the quality of education in science and engineering.

Graduate Fellowships

Since 1952 the Foundation has offered graduate fellowships each year to some of the nation's most promising and talented students. This support accelerates the students' progress toward becoming high-level contributors to the nation's scientific and technological enterprise. Foundation fellowships are flexible—they go to individual students who then choose where they wish to study. In recent years there has been an emphasis on awards to minority students to enhance their opportunities for science and technology careers.

In FY 1982, offers were extended to 555 individuals for three-year graduate fellowships. In addition, 1,052 persons continued their fellowships from previous years. In the FY 1982 competition, another 794 individuals received Honorable Mention. Experience shows that this NSF citation serves as a very high endorsement and quite often helps students get support from other sources.

Following are four examples of work by those awarded fellowships in FY 1982:

- *John E. Vidale*, in geophysics at the California Institute of Technology, is investigating earthquakes through the study of seismology and after-shock patterns. He has already done research on the seismicity of the New Hebrides trench.
- *Anne M. Kirkland*, in electrical engineering at MIT, is interested in digital signal processing and optical and microwave transmission.
- *Jeffrey L. Eppinger*, in computer science at Carnegie-Mellon University, plans to study algorithm design, computer systems, and the design of personal work stations. He has already done empirical research on computer program branching.
- *Martha C. Hayden*, in genetics at the University of Washington, Seattle, plans to investigate DNA cloning techniques to seek relationships between gene structure and function.

Table 6
Office of Scientific and Engineering Personnel and Education*
Fiscal Year 1982

(Dollars in Millions)

	Fiscal Year 1982	
	Number of Awards	Amount
Scientific Personnel Improvement	1,439	$16.75
Science Education Development and Research	69	2.67
Science Education Communication	3	1.19
NSB Commission on Precollege Education in Mathematics, Science, and Technology	—	.29
Total	**1,511**	**$20.90**

*Formerly the Directorate for Science and Engineering Education

SOURCE: Fiscal Year 1984 Budget to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

NATO Postdoctoral Program

To promote closer collaboration among the scientists of the North Atlantic Treaty Organization, NSF administers a postdoctoral fellowship program for the U.S. Department of State. Awards are made each year so that young scientists can do postgraduate research in foreign countries for 9 to 12 months. In FY 1982, 49 individuals received awards for advanced study and research in Canada, Israel, and 12 European countries.

In a parallel effort, the Foundation provides travel funds so that U.S. graduate and postdoctoral students can attend NATO Advanced Study Institutes. Candidates competing for these awards are nominated by the appropriate director of the European institutes, and NSF makes the final selection. In FY 1982, 55 students attended the institutes through this support.

NSB Commission on Precollege Education in Mathematics, Science, and Technology

Precollege achievement and participation in science and mathematics is declining, yet our society is becoming ever more technology oriented. In response to the challenge of revitalizing our educational efforts, the National Science Board established a Commission on Precollege Education in Mathematics, Science, and Technology in April 1982. This Commission aims to explore what governments and private organizations, professional groups, and individuals can do to improve mathematics, science, and technology education. It will also come up with a set of ideas, options, and strategies to improve the quality of precollege science and math education in this country.

This Commission is not meant to be another study group. Rather, the 20-member body will develop an action plan for all sectors of society. This plan should help our educational systems—both formal and informal—prepare all citizens to live, work, and participate fully in the society of the future.

At its first meeting in July 1982, the commission articulated these goals for America's educational systems:

- To continue to develop and broaden the pool of students who are well prepared and highly motivated to pursue advanced careers in mathematics, science, and engineering.
- To widen the range of high-quality math, science, and technology educational offerings so that more students can choose technically oriented careers and professions.
- To raise the general science and technology literacy of all citizens.

The commissioners, representing a wide variety of fields, began working in four task groups focused on: (1) federal, state, and local governments; (2) primary educators; (3) indirect facilitators of the educational process, such as radio, television, and the press; and (4) colleges and employers who receive students from the system. The task groups have sought the views of a wide range of individuals and organizations on improvements or changes needed in our precollege educational systems. At the same time, the commissioners have been looking at a variety of existing programs that offer high-quality precollege experiences in scientific and technical fields, to see which of these might merit adaptation elsewhere.

An interim report will follow the early analysis and identification phase. Then, with the knowledge gained from their work, the commissioners will draw up recommendations for action. A final report will come out near the end of 1983.

National Science Board Commission. In photo at left members of the Commission on Precollege Education in Mathematics, Science, and Technology are sworn in July 9, 1982 by then-NSF director John B. Slaughter (2nd from right). In second photo Lewis Branscomb, chairman of the National Science Board and a Commission member, addresses the group. Seen at far right (at the table) are Commission co-chairs Cecily Cannan Selby and William T. Coleman, Jr.

Model science center. These students are learning at the Fernbank Science Center in Atlanta, Georgia. The National Science Board's Commission on Precollege Education in Math, Science, and Technology has identified Fernbank as a model of innovative science education. Atlanta students of all ages (and some from other parts of the state as well) go there to work for several months at a time. They benefit from both modern equipment and exemplary teaching by working researchers. (Photos by Pat Olmert)

Continuing Activities

Research Apprenticeships for Minority High School Students

In FY 1982, awards went to 2[illegible] colleges, universities, and other organizations for these research apprenticeships. The grants will enable some 423 students to have the experience and excitement of working with professional scientists in their laboratories.

During the summer, the students will do research with scientists, attend seminars, and go on field trips. Academic-year activities may include further part-time research at the grantee college or university, study at the student's high school to prepare for local or national science fairs, presentations about the summer science experience to high school peers, or work as laboratory assistants. Grants provide modest stipends for the students and nominal amounts to the grantee institutions to cover costs associated with student activities.

NSF-Industry Cooperative Program

In recent years the Foundation has played a key role in the rapidly expanding use of computers for education and related activities. For example, the BASIC computer language was developed as part of a science education project at Dartmouth; the LOGO computer-aided instruction language and the PLATO and TICCIT systems for computer-assisted instruction also received Foundation support at MIT, Illinois, and the Mitre Corporation respectively. Today these prototype activities have become the locus of intensive private-sector development and investment.

In FY 1982, NSF's involvement in the area of computers in education was unusual. The Foundation funded models of computer-based instructional material for education in the sciences and engineering, using computers donated by manufacturers. Five companies (Apple, Atari, DEC, IBM, and Radio Shack) participated. They contributed a combined total of about $900,000 in computer equipment, and NSF added about $850,000. The gifts were unconditional, and the program was designed and operated exclusively by the Foundation according to its usual procedures. About 300 proposers competed for approximately 60 awards.

Other NSF/industry efforts included these:

- Projects in astronomy, physics, biology, and chemistry will develop approaches in using the personal computer for laboratory activities such as simulations, collecting data, and preparing reports.
- Several projects will develop materials and strategies to help precollege math and science teachers learn how to use computers in their classrooms.
- Robotics, computer-aided design, and computer-assisted manufacturing are some of the topics addressed in 18 engineering projects.

"3-2-1 Contact." Young students watch this popular children's series on public television. The show has reached some 30 million viewers; in fiscal year 1982 production began on its fourth season. Second photo shows an interview for one of the early 3-2-1 programs: A cast member (right) visits with an astronomer at Arecibo Observatory in Arecibo, Puerto Rico. (Photos courtesy of Children's Television Workshop.)

Other Continuing Awards

Despite the termination of most education programs, several hundred NSF projects continued under earlier funding. Among these were hundreds of grants to colleges and universities to upgrade the content and techniques of science education, primarily at the precollege and undergraduate levels. Many involved the introduction of new instruments and computer simulation, as well as locally originated curriculum and institutional changes.

A few outstanding projects with prior NSF commitments for continued funding received monies in 1982. Among these were some of exceptional significance and impact:

- Production began on another season of the children's television series "3-2-1 Contact." At this writing almost 30 million persons have seen the series, and nearly a third of a million teachers have received special teacher's guides to go with the program. A number of science museums have begun special weekend activities to capitalize on the enthusiasm generated by "3-2-1," and the Girl Scouts of America have started a special series of badges based on the program. More than 10 thousand badges have been awarded to girls in the District of Columbia alone.

- Computer-aided manufacturing and design is one of the most important and rapidly changing new industrial applications of technology. The pace of change is itself a very serious problem for engineering schools; they face great challenges in revising curricula and in acquiring equipment and software that match the state of the art and changes in industrial practices. In 1982, one NSF project based at the University of Virginia set up a consortium of major engineering schools to exchange educational materials and cooperate in building up a core of common curriculum materials.
- Similarly, the art of computer design and the techniques of computer display are changing rapidly. A substantial number of continuing projects aim to transfer these techniques from the laboratory to the classroom. Such efforts have a special importance in light of the intense international competition for leadership in automated design and manufacturing.
- In recent years, there has been progress in understanding the process of early learning and comprehension. A number of Foundation projects have focused on summarizing and integrating cognitive development theories so that they can be applied effectively to the practical problems of science education.
- While not necessarily receiving additional funds in FY 1982, the four Resource Centers for Science and Engineering continued operations begun in earlier years. These centers are at Atlanta University, the University of New Mexico and New Mexico State University jointly, the University of Puerto Rico, and City University of New York. They are working to promote participation in science and engineering by minorities and persons from low-income families. The centers sponsor a variety of activities that include research, development of research-training programs, short courses for high school teachers and students, and activities at the undergraduate level. Each is a central point for regional groups of schools and colleges, and each center also eases the transition of its students into science and engineering study.

Liaison and Information

In addition to keeping prior financial commitments, the Foundation works to provide accurate, complete, and up-to-date information in response to many inquiries about the current state of science and engineering education in this and other countries. These inquiries come from federal, state, and local governments; educational institutions; and organizations and individuals concerned about education problems and their potential effects—in both the long and short term.

The Foundation continues to be a principal resource for writers, legislators, planners, and researchers who are concerned with such topics as teacher shortages, minority participation, student achievement, international comparisons, or federal and regional funding. For example, NSF published "Science and Engineering Education: Data and Information" (an update of the 1980 publication "Science Education Database"), probably the most comprehensive collection of information on this topic. This new edition was prepared as a special report to the NSB Commission on Precollege Education in Mathematics, Science, and Technology.

Similarly, the Foundation has worked with the National Commission on Excellence in Education, which is examining overall questions of educational quality in this country. Mathematics and science are among the primary areas of concern, so this group and the National Science Board's Commission have complementary interests and roles. There has been close liaison between the two; the NSB group will strive to continue this connection and to carry forward many recommendations of the Excellence Commission.

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Coordinated Agency-Wide Research Activities

7

NSF's responsibility for the health and strength of the nation's science and engineering activities extends beyond individual disciplines; it goes to the welfare of the entire science and engineering enterprise. This enterprise faces problems that cut across many disciplines, yet are not the immediate responsibility of any one. Thus several NSF activities have been grouped under Coordinated Agency-Wide Research Activities. These programs, described below, are designed to:

- Analyze and give information on major topics associated with or affecting NSF support for science and engineering research.
- Ensure that the full range of human resources in science and engineering is fully tapped. This means, for example, that women and minorities should have ample opportunity to contribute.
- Offer opportunities for all states and regions to participate in science and engineering research opportunities.
- Give U.S. scientists a vehicle through which they can participate in the International Council of Scientific Unions.

Two- and Four-Year College Research Instrumentation Program

The purpose of this program is to provide research instrumentation to faculty members at colleges and universities that lack (or have very small) doctoral programs in science and engineering. They may ask for instrumentation costing up to $35,000. The equipment may aid research by an individual investigator but often is shared by several researchers.

Institutions eligible for grants have substantial undergraduate programs in science, mathematics, or engineering but grant fewer than 20 Ph.D.'s annually in these areas. In fiscal year 1982 the program supported the work of scientists in 66 different institutions. Eighty-five awards were made, with an average size of about $23,000.

The largest number of awards were for research in chemistry. For example, Michael P. Doyle, William S. Mungall, and others at Michigan's Hope College are using a gas chromatography system for research in catalysis and related subjects. Their department has a strong record of involving undergraduate students in high-quality research projects. At Furman University in South Carolina Noel Kane-Maguire, L. S. Trzupek, and others are also looking into catalysis—using a nuclear magnetic spectroscope acquired through this program.

Modern research in biology extends from laboratory to field investigations. This program has aided both types, for example, by providing a high-quality research microscope for joint use by Diane Cope Peabody of Bridgewater (Massachusetts) State College and Robert B. Peabody at nearby Stonehill College. Her research is on fungi; his is in animal genetics. At Reed College (Oregon), Peter J. Russell is also conducting botanical (fungal) genetic research. He is using a centrifuge, freezer, and other equipment provided from the program to do his recombinant DNA studies.

For field studies, often the major need is a means to make many reliable measures of environmental data and then process them. An example of this is the anemometer and oxygen meter used by James L. Gooch of Juniata College (Pennsylvania) for studies of fresh-water crustaceans.

In addition to grants for research in chemistry and biology, work in about a dozen other fields has been supported. They include astronomy, engineering, geology, physics, and psychology.

Visiting Professorships for Women

NSF launched this program in fiscal 1982. Its aim is to encourage full use of the nation's scientific and technical resources by increasing the participation of women scientists and engineers as visiting professors at academic institutions. This year 17 women were selected for awards that average $55,760; they will do research and teach in areas of science, engineering, and mathematics supported by NSF research programs. They will also offer advice, counsel, and mentorship to women at their host institutions.

The backgrounds of the awardees are varied: 14 are from academia, and there is one each from industry, the federal government, and public museums. Two of those from academia are full professors, six are associate professors, three are assistant professors, and three have nonprofessorial positions.

Jill C. Bonner, a full professor of physics at the University of Rhode Island, is an example. She will spend 12 months at Michigan State University. There she will study "Two-Dimensional Magnetism: Statics and Dynamics," teach a special course, participate in research seminars, and work with women's groups on campus.

Another example is Delores M. Etter,

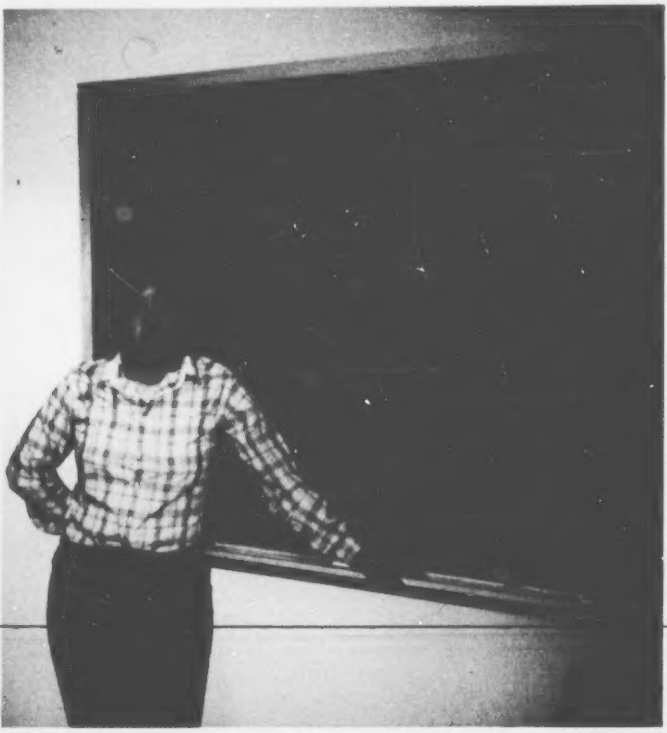
See table 5 for budget information on Coordinated Agency-Wide Activities.

an associate professor in the Department of Electrical and Computer Engineering at the University of New Mexico. She will do research at Stanford University on "Time-Delay Estimation Using a Modified Adaptive Delay Algorithm." During her 12-month visiting professorship, Etter will also teach an introductory course in digital signal processing, take part in undergraduate and graduate seminars, and advise female students on engineering careers.

A third recipient is Ann L. Hollick, director of international commodities at the U.S. Department of State, who will spend 12 months at the Massachusetts Institute of Technology. Hollick, whose doctoral degree is in political science and international relations, will study "Planning Foreign Policy in the Area of Science and Technology" and will give seminar and guest lectures on this topic.

The other 14 awardees, their fields, and host institutions are as follows:

- *Carolyn L. Attneave,* psychology, St. Vincent College
- *Susan K. Avery,* atmospheric science, University of Colorado at Boulder
- *Bonnie E. Blustein,* history of science, Northwestern University
- *Marjorie Crandall,* biology, University of California at Los Angeles
- *Linda K. Denoyer,* astronomy, Colgate University
- *Lynda J. Goff,* biology, Brown University
- *Patricia A. Gowaty,* biology, Cornell University
- *Carole E. Joffe,* sociology, University of Pennsylvania
- *Marian A. Lowe,* chemistry, University of Southern California
- *Gertrude F. Neumark,* physics, Columbia University



Visiting Professors. Psychologist Carolyn Attneave (above) receives honorary degree at Pennsylvania's St. Vincent College, where she will teach and do research for a year. Attneave, an American Indian, is from the University of Washington in Seattle. Gertrude Newmark (left) is the only one of the 17 visiting women professors for 1982 who comes from industry. A senior physicist at Phillips Laboratories in New York, she will do research at Columbia University, along with teaching two courses and advising women students of science and engineering. Mathematician Lai-Sang Young (right), from Michigan State University, will conduct both research and seminars at the University of North Carolina under her award. Fiscal year 1982 was the first year for this program.

- *Prudence M. Rice*, archaeology, University of Chicago
- *Susan Simkin*, astronomy, University of Wisconsin
- *Janis D. Young*, biochemistry, Hunter College
- *Lai-Sang Young*, mathematics, University of North Carolina at Chapel Hill.

Minority Research Initiation

This program gives research support to faculty members who are U.S. nationals and members of ethnic or racial minority groups that have low participation rates in science and engineering research. Proposals are accepted from eligible researchers at any U.S. college or university if they have not received previous federal research support as faculty members.

According to 1979 data, Blacks and other minorities accounted for less than 1 percent of employed physical scientists, 4.4 percent of mathematical scientists, 2.8 percent of life scientists, 1.3 percent of computer specialists, and 1.9 percent of social scientists. Through this program, the Foundation continues one of its general goals—to enhance research opportunities in science and engineering for minorities.

The Foundation awarded 16 MRI grants for a total of $1.43 million in FY 1982. The average award size was $89,000. Five grants went to predominantly minority institutions: City University of New York/City College, Fayetteville State University, Jackson State University, Tuskegee Institute, and the University of Puerto Rico. Other awards were made to Arizona State University, California State University—Los Angeles, Johns Hopkins University, Rutgers, University of Arizona, University of California—Riverside, University of Kansas, University of Kentucky (2), University of Massachusetts, and the University of Virginia.

Geographically, seven awards went to colleges and universities in the South, three in the East, four in the West, one in the Midwest, and one to the University of Puerto Rico. Women scientists got two awards, Hispanic males five, and Black males nine.

One MRI project for FY 1982 will study how the normal development and function of the visual system can be affected by a variety of biological or chemical agents such as monosodium glutamate (MSG), commonly used as a food additive. The study will analyze measurements of cell survival and morphology and of glutamate and energy metabolism. This research should give additional insight on key elements of neuronal and nonneuronal interactions.

Another project will examine the general cognitive abilities of bilingual children. The study will measure communicative and structural linguistic proficiency as well as general cognitive ability in a population of 100 Spanish/English bilingual children. Results from this project will further our understanding of the relationship of bilingualism to intellectual and academic performance.

A third effort will seek to expand current knowledge of luminescence and electron transfer. Other MRI projects will center on a theoretical-physics study of exotic particles called fermions, a look at social interactions in three-generational Black families, a mathematics study of representation theory, an understanding of major field choices and career aspirations by race and sex, and development of the spinal cord.

Research Improvement in Minority Institutions

The RIMI program, established in FY 1982, gives support to improve research environments at predominantly minority institutions that have graduate programs in science or any programs in engineering (graduate or undergraduate). RIMI also responds to Executive Order 12320, which directs federal agencies to increase the ability of historically black colleges and universities to participate in federally sponsored programs.

"Predominantly minority" institutions are those whose primary mission is to educate minorities and whose student enrollments are more than 50 percent Native American, Alaskan Native, Black, Mexican American, Puerto Rican, or other minorities with low participation rates in science and engineering.

RIMI favors proposals that show how an institution can strengthen its long-range plan to develop the research capabilities of faculty and students in science and engineering. Special attention goes to projects that demonstrate an institution's commitment to research improvement through both short- and long-range use of its own resources. In addition, institutions are encouraged first to enhance technology programs that are already well advanced; the hope is that other, less-developed programs will get indirect benefits.

In FY 1982, four awards were made totaling $908,000, for an average award size of $227,000.

One project at Howard University will strengthen its semiconductor research program. Howard is the only historically minority institution in the United States that offers a doctoral degree in electrical engineering. Studies will be done to gain new knowledge about certain semiconductor materials and their microwave applications. These materials have a higher electron mobility than silicon, which leads to higher electron velocities. Those velocities will influence the development of faster computers, higher-frequency communication systems, and more computer complexity.

Another project, at Jackson State University, will use the school's chemical-physics research laboratory to study the structure and dynamics of molecular ions and other unique small molecular systems. Studies will also focus on mechanisms for energy transfer and charge transfer in thin films and solution systems. More specifically, researchers will use laser-induced emission and excitation spectroscopy of gaseous ions to analyze certain molecular reactions. These experiments will expand our understanding and characterization of interstellar clouds and planetary atmospheres.

Researchers on another project, at the University of Puerto Rico, will use a high-resolution scanning electron microscope with an energy dispersive spectrometer, which was purchased through RIMI support. They will look at polycrystalline semiconductors, selective surfaces, and modified electrodes, along with an environmental analysis on particulates and other biological studies.

At Atlanta University, researchers will develop analytical and numerical techniques for certain classes of mathematical equations, including difference, matrix, singular operator, and integro-differential equations. These studies will be the initial phase of an institutional research program in applied mathematics and physics. That program will formulate mathematical models and develop computer simulation techniques for use in the biological, physical, and social sciences and in engineering.

Jackson State project. Through the Foundation's RIMI program (Research Improvement in Minority Institutions), students at this university are able to do important molecular research in Jackson State's chemical-physics laboratory. Here a professor (center) and undergraduate student discuss use of the pulsed laser in their experiments. Their work will help us understand more about interstellar clouds and planetary atmospheres.

Experimental Program to Stimulate Competitive Research

The aims of this program are (1) to improve the overall quality of science and engineering in participating states and (2) to increase the ability of researchers in those states to compete successfully for federal research funds through the peer-review process. The program is entering the third year of a five-year research improvement effort in five states: Montana, West Virginia, South Carolina, Maine, and Arkansas. Results include these:

- The recruitment of the science and engineering faculty in participating institutions has improved. For example, the University of South Carolina has hired three new faculty members, including a noted synthetic organic chemist and an internationally known physicist from Norway. The earth sciences program at the University of Maine has attracted two nationally known earth scientists to its staff; this has caused an increase in the number of scientists seeking cooperative research efforts with the university in Appalachian geology.
- The interaction between scientists and engineers in participating states and their nationally known peers has increased markedly. The South Carolina Advisory Committee, for instance, has used about 125 nationally recognized researchers to help select targeted disciplines and faculty. West Virginia is offering its participants minisabbaticals that let them work up to one month a year outside the university. More than 50 well-known researchers visited Montana to work with faculty and present seminars during the past year.
- The individuals involved are getting more recognition for their work, and their research productivity has gone up. For example, a Maine scientist has developed an innovative method—one much more sensitive than conventional techniques—to measure nitrates in seawater.
- Basic research has taken on greater importance, and the research "spirit" is higher than ever in the participating states.

International Council of Scientific Unions

The Foundation supports the participation of the U.S. scientific community in international cooperative activities through the International Council of Scientific Unions. ICSU sponsors congresses and symposia, publishes data and information, establishes nomenclature and other standards, organizes summer schools and training programs, promotes contact with developing countries, and develops multidisciplinary research programs. Ranging from earth and space sciences through physics, chemistry, mathematics, environmental research, and the many fields of the life sciences, these ICSU activities involve thousands of scientists in more than a hundred nations.

Atmospheric research studies have advanced our knowledge about the physical processes of the atmosphere, as well as interactions between oceans and atmosphere. The information collected from ICSU programs, including ocean monitoring, will be used to improve the validity of weather forecasts on a longer-range basis. ICSU representatives also helped refocus the World Climate Program to highlight climate issues in terms of food, water, energy, predictability, and human influences, including carbon dioxide.

A major activity during the past year was a global review of research and development on the disposal of high-level nuclear waste on land and sea. At the urging of American chemists, an international conference program was inaugurated to focus the results of chemical research applied to world needs. Areas addressed included alternatives to petroleum, world food supplies, future sources of organic raw materials, and ocean resources.

A major study of the lithosphere was launched. It focuses on the application of geological sciences toward developing mineral and energy resources, reducing geological hazards, and preserving the environment. During 1982, the observational phase of the Solar Maximum Year took place and compilation of data continued. Also begun were anniversary celebrations of the Polar Years and the International Geophysical Year. A special workshop analyzed unpublished data from multiship research cruises making biological investigations of marine systems and stocks in Antarctica.

Alan T. Waterman Award

This award recognizes an outstanding young person in the forefront of science. In addition to a medal, the recipient receives a grant of up to $50,000 per year for a maximum of three years. Candidates for the award must be U.S. citizens 35 years of age or younger, or not more than five years beyond receipt of the doctoral degree on December 31 of the year they are nominated. Emphasis is on a candidate's record of completed, high-quality, innovative research—work that shows outstanding capability and exceptional promise for making significant achievements in the future.

Alan T. Waterman Award winner. Richard Axel, of the Columbia University Institute of Cancer Research, is the seventh recipient of this annual Foundation honor. Axel's novel methods of introducing genes into mammalian cells are speeding up discoveries in the field of genetic engineering. The award, named for NSF's first director, will further the work of Axel's laboratory.

Seven persons have received this award: two mathematicians, two physicists, one paleobiologist, one chemist, and one biologist. The seventh recipient, Richard Axel of Columbia University, was honored in 1982 for devising a novel procedure to introduce genes from virtually any source into mammalian cells. Gene transfer now allows scientists to analyze the mechanism regulating gene expression in an appropriate cellular environment. This information is a prerequisite to a rational approach toward gene therapy.

One of the major unsolved problems of modern biology is the mechanism of gene-controlled differentiation—that is, how a single fertilized egg can give rise to an individual with specialized liver, nerve, muscle, and kidney cells. We know that the DNA in each of these cells is identical, so the critical question is this: How are some genes turned on or off in some cells while other genes are turned on or off in other cells? The advent of DNA recombinant technology allows the preparation of large quantities of isolated genes and an examination of their structures. The technology permits analysis of DNA that regulates genes—i.e., turns them on or off.

Axel analyzed gene regulation by introducing DNA into mammalian cells. He then observed how it functioned—that is, how DNA was expressed. This approach has been of such great value that some scientists are using it to study the transformation of cancer cells, how viruses infect cells, and what regulates the immune response in other cells. Axel is applying the techniques of recombinant DNA technology to an understanding of how the nervous system is organized and how this organization is responsible for generating very simple behaviors.

Other Awards

The Foundation also gives a Distinguished Public Service Award and a Meritorious Public Service Award. In fiscal year 1982 these honors went to William T. Golden and Ewaugh Fields, respectively.

Since the Truman Administration, Golden has advised the U.S. government on science activities, and he has long been a leading advocate of a strong science adviser to the President. When the Foundation was created, he had a role in determining its future programs and direction, through his advice and counsel with the U.S. budget director. Golden's recommendation that Alan Waterman be named the first head of NSF was influential and perhaps decisive.

Golden has served in many public and private capacities to advance the pursuit of scientific learning. For example, he has been a board member of the American Association for the Advancement of Science since 1969. He is an editor of *Science Advice to the President*, the reflections of eight former science advisers to the Executive Office.

Ewaugh Fields has had a distinguished career as a mathematician, educator, and administrator. Over the past 10 years she

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NATIONAL SCIENCE FOUNDATION

Other award winners. William T. Golden (left) has advised the U.S. government on science matters since the Truman Administration. A prominent advocate of scientific learning, he received the Foundation's Distinguished Public Service Award for fiscal year 1982 (photo by Garfield). In second photo, John B. Slaughter, NSF Director until October 1982, presents the Meritorious Public Service Award to mathematician and educator Ewaugh Fields. She has been a leader over the past 10 years in the Foundation's efforts to increase the number of minorities and women in science and technology.

has played a key leadership role in the Foundation's efforts to increase the number of minorities and women in scientific and technical careers.

Now a dean at the University of the District of Columbia, Fields has served the Foundation in many ways. For example, from 1977 to 1981 she chaired the NSF Advisory Committee for Minority Programs in Science Education. Fields is now on the Committee on Equal Opportunities in Science and Technology. The U.S. Congress set up this group in 1980 to advise NSF's director on policy and program concerns involving minorities and women.

NSF Planning and Evaluation

Planning at NSF is a cyclical process that develops, collects, and uses information on the agency's goals, structure, current activities, constraints, and mandates. This information enables the Foundation to set priorities, plan program activities, identify staff and support needs, and deal with major policy issues.

To supplement the extensive analysis done by inhouse staff, the program supports a small number of extramural studies. In 1982 these studies focused on the following areas.

- Research price indexes in different academic disciplines, to promote understanding of the actual costs of scientific research.
- Carbon dioxide in the atmosphere.
- A key word thesaurus for research proposals.
- Early identification of emerging fields of scientific inquiry.
- The need for large-scale computing resources to support scientific research.
- Science in the international setting.
- Instrumentation requirements in the plant sciences.

Policy issues in the funding and performance of scientific activities are of continuing concern to NSF. Examples of such issues include the allocation of support among research areas; how science and engineering relate to achieving national goals; more effective ways to support science and engineering; the economic and social consequences of that support; ways to develop the nation's technology potential; and opportunities for, and constraints on, the development of technical fields.

An important planning function is to give substantive support to certain committees and special groups serving the National Science Board, NSF's policymaking body. In this connection the following work has been done:

- Planning and Policy Committee—The NSB Planning and Policy Committee reported on its activities from May 1981 to May 1982. This report is an instrument to evaluate the committee's policy decisions and recommendations and to raise strategic issues.

- Historically Black Colleges and Universities—A report called ***Resources Supporting Scientific Activities at Predominantly Black Colleges and Universities*** responds to the President's Executive Order of September 1981. That order made a commitment to strengthen the capabilities of historically Black colleges and universities. The report details overall levels of federal funding to 105 predominantly Black colleges and universities, with particular emphasis on their science and engineering activities. It covers general funding trends from fiscal years 1973 to 1980 and gives information about the number of graduate students and full-time faculty in science and engineering. The report also has individual profiles of federal funding at each of the institutions, along with information about their scientific and engineering personnel by field, degree, and sex.
- Minorities and Women in Science and Engineering—The Foundation has a continuing interest in human resources, including the role of minorities and women in science and engineering. In addition to the study on predominantly Black colleges and universities, NSF has analyzed the response to a new program of visiting professorships for women.
- Annual Board Report—The Fourteenth Annual Report of the National Science Board, ***University-Industry Relationships: Myths, Realities, and Potentials***, was sent to the President and published. Several studies of university-industry research interactions were commissioned to provide background information for this report. These studies are being made available as a separate publication of the National Science Board.

Evaluation studies give the NSF director information on the effectiveness of major Foundation programs and the integrity of the award process. They form the basis of his oversight responsibilities in these areas and provide groundwork for budgetary or policy decisions. Program evaluations are designed internally but often carried out by contractors.

In September 1980, the Senate Appropriations Committee directed NSF "to secure a third party to develop a methodology for postresearch evaluation of scientific research endeavors." In response, NSF contracted with the National Academy of Sciences, as suggested by the Senate. An NAS report on evaluation methods was sent to the Appropriations Committee in March 1982. The next step in this effort is an evaluation of NSF's chemistry program.

Science and Technology Reports

The Foundation is required by law to prepare several reports for the Congress. Two of these are required by the Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94-282). In complying with this act, NSF did the following:

- In January 1982 the director transmitted ***The Five-Year Outlook on Science and Technology, 1981*** to the Congress. This report describes the potential impact of developments in science and technology on problems of national concern over the next five years.
- In April the President transmitted to Congress the ***Annual Science and Technology Report to the Congress, 1981***, a comprehensive statement of the Administration's national science and technology policy. In helping the President's Office of Science and Technology Policy prepare this report, NSF convened a series of panels to explore current and emerging issues. The panel deliberations are summarized in eight working papers, assembled in ***Emerging Issues in Science and Technology, 1981: A Compendium of Working Papers for the National Science Foundation***.

Ocean Drilling

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The year 1982 was an exceptional one in ocean drilling. NSF's newly formed Office of Scientific Ocean Drilling not only continued to manage the Deep Sea Drilling Project but also began to focus on a long-term Advanced Ocean Drilling Program, with plans to use the government-owned vessel *Explorer*.

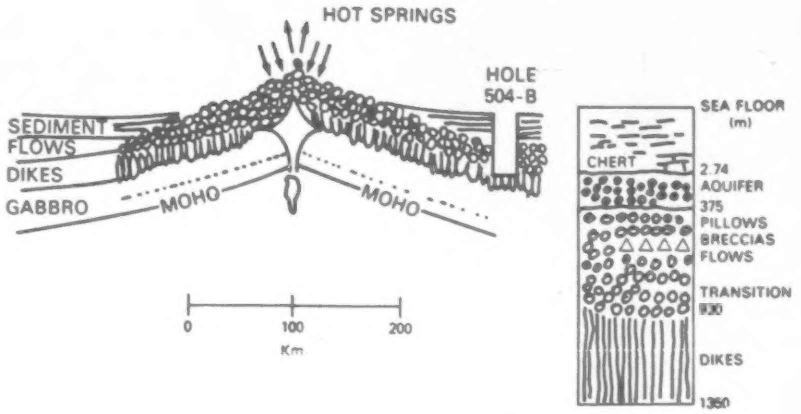
Deep Sea Drilling Project

The major purpose of this project is to explore the ocean lithosphere by means of subbottom coring. To accomplish the coring program, the drilling vessel *Glomar Challenger* was commissioned in 1968. As of August 1982, a total of 989 holes had been drilled at 584 sites on 87 cruises in all the world's major ocean basins. Scientific planning is managed by the Joint Oceanographic Institutions, Inc., with advice from scientific committees and panels of the Joint Oceanographic Institutions for Deep Earth Sampling. The Scripps Institution of Oceanography is the prime contractor for scientific operation of the project.

Seven legs (82-88) took place during fiscal 1982. Three of these involved the composition of ocean crust (leg 83), the geology of active margins and associated deposits of methane gas and water called clathrates (leg 84), and the interpretation of paleoenvironments (leg 85).

The leg 83 researchers, working in the eastern equatorial Pacific, went to a total depth of 1,350 meters below the sea floor, or 1,075.5 meters into basement. They penetrated almost twice as deep as ever before into oceanic crust, doing an extensive set of geophysical experiments.

The major purpose of this deep penetration was to test an ophiolite model previously established on land. Ophiolites are layers interpreted to represent sections of old oceanic crust generated at midocean ridge spreading centers; these sections have been attached to land during collisions of plates as they move over the earth's surface.



Leg 83 work. Researchers looking into the composition of ocean crust deepened drill hole 504-B in the Costa Rica Rift area. They sampled layers of various types of ocean crust, seen here. (Dikes, gabbro, brecchias, and chert are types of rock; pillows and flows are lava formations. Moho is the point beneath the ocean floor where a seismic transition marks a change from ocean crust to mantle.) Leg 83 penetrated almost twice as deep as ever before—1,350 meters below the sea floor.

The recovered core showed interesting comparisons with the ophiolite land model, confirming, for example, that the upper structure of ophiolites is found in ocean crust. However, there were also differences. For one thing, the ophiolite rocks found on land generally reequilibrate under certain temperature conditions. But leg 83 basalts display only partial recrystallization, showing they have not reached equilibrium. Also, leg 83 rocks do not progressively grade downward into increasingly higher temperature rocks. Some of the lowest temperature-alteration minerals and least-altered rocks are found in the deepest cores.

Earlier work, during legs 69 and 70, had discovered an underpressured aquifer in one hole. Leg 83 scientists verified that this aquifer was located at the base of the porous basalt flows and was still drawing ocean-bottom water downward into the ocean crust two years later. Over the two-year period, the rate of downflow slowed from 6,000 to 1,500 liters per hour. Approximately 50×10^6 kilograms of seawater were drawn into the crust in those two years.

See table 4 for budget information on Ocean Drilling.

During leg 84, the *Challenger* drilled 11 holes at six sites in the Middle America Trench off Costa Rica and Guatemala. The major purpose of this drilling was to strengthen the tie between onshore and offshore geology. Prime objectives were (1) to establish the age and structure of the continental framework that forms the landward slope of the trench off Guatemala, and (2) to study the origin and occurrence of gas hydrate in the marine environment.

At four sites where slope sediments were penetrated, the basement seems to be sections of an ophiolite. The upper surface of the basement is covered by slope sediments ranging from perhaps Cretaceous to early Miocene in age. Researchers found no age progression of younger material at the base to older at the top of the slope, as occurs off the coast of Mexico. Thus it appears that tectonically disrupted ophiolitic rock lies under the Guatemalan margin.

A second aspect of leg 84 drilling was to study natural gas hydrates called clathrates. These are compounds of water and light hydrocarbon gases, mainly methane. At low temperatures and high pressures (ocean-bottom conditions), they are chemically stable solids. Their physical appearance is like that of ice; when confining pressure is removed—such as when they are brought to the surface in cores—the clathrates fizzle as they break down chemically and yield the bound gases. At room temperatures and pressure, these icelike structures melt to residual water while yielding many hundreds of times their volume in gas.

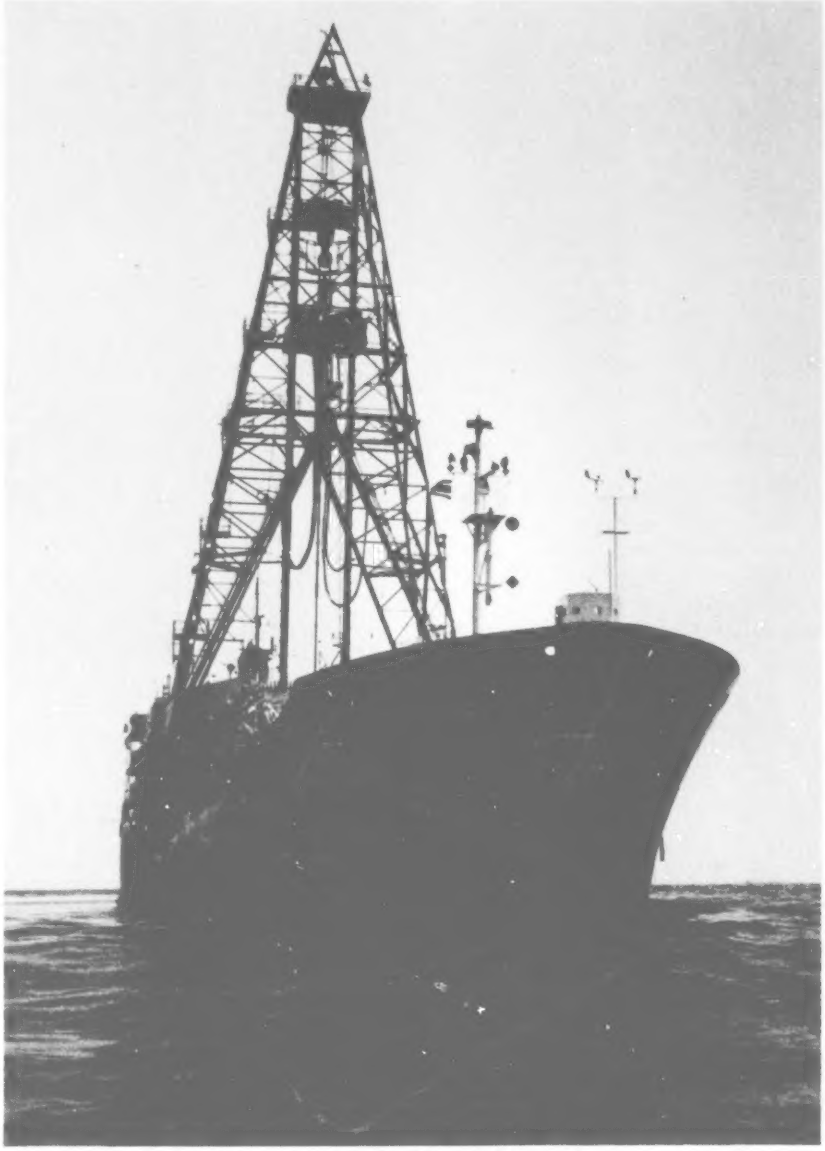
An important find was a layer of massive, white, largely methane hydrate approximately three meters thick. Samples of this have been preserved for laboratory study. Downhole logs contain the first demonstrated log response of cored gas hydrates in oceanic sediment; they also provide the first *in situ* measurements of the sonic velocity and density of those hydrates.

Leg 85 addressed the interplay of three fundamental factors and how they have shaped the history of deposits in the eastern and central Pacific: (1) tectonics and the spreading sea floor, (2) biological productivity, and (3) changes in oceanographic conditions throughout the water column.

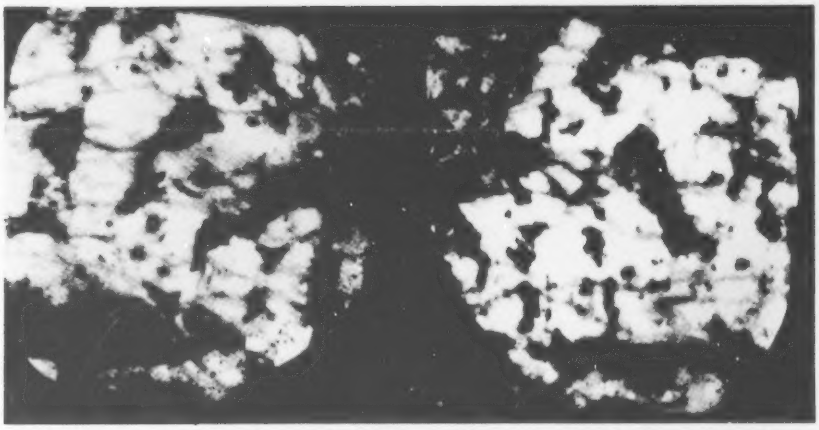
All of the sites drilled on the Pacific Plate have migrated from relatively shallow (3,000-meter) depths in the eastern Pacific, south of the equator, to deeper (4,000 to 6,000-meter), more western locations at or north of the equator. The most striking factor affecting these sites is the strong east-west productivity gradient. At the eastern sites sedimentation and accumulation rates are extremely high (often more than 50 meters per million years), with the rates decreasing to the west. This gradient is especially strong during the mid-Miocene to early Pliocene. It is dominated by the production of siliceous microfossils (mostly diatoms) in the east.

Though it is less pronounced than the east-west gradient, there is a latitudinal change in the depositional environment. Sedimentation rates decrease northward away from the equator. The most pronounced gradient is found in the early Miocene; this is consistent with previous compilations of equatorial Pacific sedimentation patterns.

Temporal variations in productivity, dis-



Glomar Challenger. Researchers are using this vessel for subbottom coring in the Deep Sea Drilling Project, which has drilled in all the world's major ocean basins. There were seven research trips, or legs, in fiscal year 1982.



Clathrates. Leg 84 drillers brought up these samples of a massive natural gas hydrate, or clathrate, found near Costa Rica and Guatemala. These compounds of water and light hydrocarbon gases look like ice, but at room temperature and pressure they expand, melt, and yield many hundreds of times their volume in gas (mainly methane). Ocean drillers were able to get key onsite measurements of the sonic velocity and density of these important natural resources.

solution, and deep-sea erosion are superimposed upon these major factors. For example, a major shift in the nature of carbonate deposition at the middle-late Miocene boundary occurs at three of the sites drilled. Material older than late Miocene has a relatively constant high carbonate content, whereas material deposited after the middle Miocene fluctuates between high and low carbonate content. Associated with this shift from carbonate-silica cycles to high carbonate sediments are significant changes in physical and magnetic properties of the sediment. This shift has been attributed to worldwide cooling and to a change from an Atlantic to a Pacific sink for silica.

A second example is the occurrence of hiatuses or intervals of greatly reduced sedimentation. One such hiatus correlates with the Eocene/Oligocene boundary. It has been associated with the separation of Antarctica from Australia and with enhanced bottom-water circulation resulting from Antarctic glaciation. Other intervals were found at the Oligocene/Miocene, in the middle part of the lower Miocene, and in the early late Miocene.

A most intriguing result of leg 85 drilling is the possibility of seismically tracing the middle/late Miocene boundary, which greatly affected much of the central equatorial Pacific. The implications of this work for paleoceanography are tremendous.

Advanced Ocean Drilling Program

In the past fiscal year, the Office of Scientific Ocean Drilling presented to the National Science Board plans for a successor program to the Deep-Sea Drilling Project—the Advanced Ocean Drilling Program. The Board endorsed the idea that scientific ocean drilling will continue to be a key part of future basic research in the earth and ocean sciences, and it recommended conversion of the government-owned *Explorer* to a drilling ship.

Current plans call for possible conversion of the *Explorer* during fiscal years 1983 and 1984, with a drilling program to begin in fiscal year 1986. The *Explorer* also promises a longer life for the needs of the scientific community and drilling capabilities beyond those of the *Challenger*.

Finally, an important aspect of this drilling program is expansion of the international participation that has proven so successful for the Deep-Sea Drilling Project.

Appendix A

National Science Board Members and NSF Staff
(Fiscal Year 1982)

NATIONAL SCIENCE BOARD

Terms Expired May 10, 1982

Raymond L. Bisplinghoff, *Vice-President for Research and Development*, Tyco Laboratories, Inc., Tyco Park, Exeter, New Hampshire

Lloyd M. Cooke, *President*, National Action Council for Minorities in Engineering, Inc., New York, New York

Herbert D. Doan, (*Vice-Chairman*, National Science Board), *Chairman*, Doan Associates, Midland, Michigan

John R. Hogness, *President*, Association of Academic Health Centers, Washington, D.C.

William F. Hueg, Jr., *Professor of Agronomy* and *Deputy Vice-President* and *Dean*, Institute of Agriculture, Forestry, and Home Economics, University of Minnesota, St. Paul, Minnesota

Marian E. Koshland, *Professor of Bacteriology and Immunology*, University of California, Berkeley, California

Joseph M. Pettit, *President*, Georgia Institute of Technology, Atlanta, Georgia

Alexander Rich, *Sedgwick Professor of Biophysics*, Massachusetts Institute of Technology, Cambridge, Massachusetts

Terms Expire May 10, 1984

Lewis M. Branscomb (*Chairman*, National Science Board), *Vice-President* and *Chief Scientist*, International Business Machines, Inc., Armonk, New York

Eugene H. Cota-Robles, *Professor of Biology*, Biology Board of Studies, University of California, Santa Cruz, California

Ernestine Friedl, *Dean of Arts and Sciences and Trinity College* and *Professor of Anthropology*, Duke University, Durham, North Carolina

Michael Kasha, *Distinguished Professor of Physical Chemistry*, Institute of Molecular Biophysics, Florida State University, Tallahassee, Florida

Walter E. Massey, *Director*, Argonne National Laboratory, Argonne, Illinois

David V. Ragone, *President*, Case Western Reserve University, Cleveland, Ohio

Edwin E. Salpeter, *J. G. White Professor of Physical Sciences*, Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, New York

Charles P. Slichter, *Professor of Physics*, University of Illinois, Urbana, Illinois

Terms Expire May 10, 1986

Jay Vern Beck, *Professor Emeritus of Microbiology*, Brigham Young University, Provo, Utah

Peter T. Flawn, *President*, University of Texas, Austin, Texas

Mary L. Good, *Vice-President*, Director of Research, United Oil Products, Inc., Corporate Research Center, Des Plaines, Illinois

Peter D. Lax, *Professor of Mathematics*, Courant Institute of Mathematical Sciences, New York University, New York, New York

Homer A. Neal, *Dean of Research and Graduate Development* and *Professor of Physics*, Indiana University, Bloomington, Indiana

Mary Jane Osborn, *Professor* and *Head*, Department of Microbiology, University of Connecticut School of Medicine, Farmington, Connecticut

Donald B. Rice, Jr., *President*, The Rand Corporation, Santa Monica, California

Stuart A. Rice, *Frank P. Hixon Distinguished Service Professor of Chemistry*, James Franck Institute, University of Chicago, Chicago, Illinois

Terms Expire May 10, 1988

(Eight Vacancies)

Member Ex Officio

John B. Slaughter (*Chairman*, Executive Committee), *Director*, National Science Foundation

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Margaret L. Windus, *Executive Officer*, National Science Board, National Science Foundation

NATIONAL SCIENCE FOUNDATION STAFF
(as of September 30, 1982)

Director, John B. Slaughter

Deputy Director, Donald N. Langenberg

Director, Office of Equal Opportunity, Perry W. Hooks

General Counsel, Charles Herz

Director (Acting), Office of Government and Public Programs, Thomas Ubois

Director, Office of Planning and Resources Management, M. Kent Wilson

- *Director, Division of Budget and Program Analysis*, L. Vaughn Blankenship
- *Director, Division of Planning and Policy Analysis*, Irwin M. Pikus
- *Director (Acting), Division of Program Development*, M. Kent Wilson

Director, Office of Audit and Oversight, Jerome H. Fregeau

Director, Office of Small Business Research and Development, Theodore W. Wirths

Director, Office of Small and Disadvantaged Business Utilization, Theodore W. Wirths

Director, Office of Scientific Ocean Drilling, Allen M. Shinn

Director, Office of Scientific and Engineering Personnel and Education, Walter L. Gillespie

Executive Director, National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, Richard S. Nicholson

Assistant Director for Mathematical and Physical Sciences, Edward A. Knapp

- *Deputy Assistant Director (Acting) for Mathematical and Physical Sciences*, Ronald E. Kagarise
- *Director, Division of Mathematical and Computer Sciences*, Ettore F. Infante

  - *Director, Division of Physics,* Marcel Bardon
  - *Director, Division of Chemistry,* Edward F. Hayes
  - *Director (Acting), Division of Materials Research,* Lewis H. Nosanow
- *Assistant Director for Engineering,* Jack T. Sanderson
  - *Deputy Assistant Director for Engineering,* Carl W. Hall
  - *Director, Division of Electrical, Computer, and Systems Engineering,* Thelma A. Estrin
  - *Director, Division of Chemical and Process Engineering,* Marshall M. Lih
  - *Director, Division of Civil and Environmental Engineering,* William S. Butcher
  - *Director, Division of Mechanical Engineering and Applied Mechanics,* Ray M. Bowen
- *Assistant Director for Biological, Behavioral, and Social Sciences,* Eloise E. Clark
  - *Deputy Assistant Director for Biological, Behavioral, and Social Sciences,* Robert Rabin
  - *Director (Acting), Division of Physiology, Cellular and Molecular Biology,* James H. Brown
  - *Director, Division of Environmental Biology,* John L. Brooks
  - *Director, Division of Behavioral and Neural Sciences,* Richard T. Louttit
  - *Director (Acting), Division of Social and Economic Sciences,* James H. Blackman
  - *Director, Division of Information Science and Technology,* Edward C. Weiss
- *Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences,* Francis S. Johnson
  - *Deputy Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences,* Albert L. Bridgewater
  - *Director, Division of Astronomical Sciences,* Laura P. Bautz
  - *Director, Division of Atmospheric Sciences,* Eugene W. Bierly
  - *Director, Division of Earth Sciences,* James F. Hays
  - *Director, Division of Ocean Sciences,* M. Grant Gross
  - *Director, Division of Polar Programs,* Edward P. Todd
- *Assistant Director for Scientific, Technological, and International Affairs,* Richard J. Green
  - *Deputy Assistant Director for Scientific, Technological, and International Affairs,* Leonard L. Lederman
  - *Director, Division of Industrial Science and Technological Innovation,* Donald Senich
  - *Director, Division of Intergovernmental and Public-Service Science and Technology,* Alexander J. Morin
  - *Director, Division of International Programs,* Bodo Bartocha
  - *Director (Acting), Division of Policy Research and Analysis,* Robert R. Trumble
  - *Director, Division of Science Resources Studies,* Charles E. Falk
- *Assistant Director for Administration,* Thomas Ubois
  - *Deputy Assistant Director for Administration,* Kurt G. Sandved
  - *Director, Division of Grants and Contracts,* Gaylord L. Ellis
  - *Director, Division of Information Systems,* Constance K. McLindon
  - *Director, Division of Personnel and Management,* Fred W. Murakami
  - *Director, Division of Financial Management,* Kenneth B. Foster
  - *Director, Division of Administrative Services,* Troy T. Robinson

Appendix B

Financial Report for Fiscal Year 1982
(in thousands of dollars)

Research and Related Activities Appropriation

Fund Availability

Fiscal year 1982 appropriation	$971,595	
Unobligated balance brought forward	771	
Recovery of prior year obligations	5,031	
Fiscal year 1982 availability		$977,397

Obligations

Mathematical and Physical Sciences:		
Mathematical Sciences	$30,489	
Computer Research	25,745	
Physics	75,323	
Chemistry	61,356	
Materials Research	79,930	
Subtotal, Mathematical and Physical Sciences		$272,843
Engineering:		
Electrical, Computer, and Systems Engineering	$25,682	
Chemical and Process Engineering	20,273	
Civil and Environmental Engineering	29,953	
Mechanical Engineering and Applied Mechanics	17,072	
Interdisciplinary Research	306	
Subtotal, Engineering		$93,286
Biological, Behavioral, and Social Sciences:		
Physiology, Cellular and Molecular Biology	$80,112	
Environmental Biology	41,990	
Behavioral and Neural Sciences	31,736	
Social and Economic Sciences	17,561	
Information Science and Technology	5,198	
Subtotal, Biological, Behavioral, and Social Sciences		$176,597

SOURCES: Fiscal Year 1984 Supplementary Budget Schedules, Fiscal Year 1984 Budget to Congress and NSF accounting records

Astronomical, Atmospheric, Earth, and Ocean Sciences:		
Astronomical Sciences	$59,097	
Atmospheric Sciences	70,339	
Earth Sciences	29,489	
Ocean Sciences	75,030	
Arctic Research Program	5,898	
Subtotal, Astronomical, Atmospheric, Earth, and Ocean Sciences		$239,853
U.S. Antarctic Program		$68,505
Ocean Drilling Programs		$20,000
Scientific, Technological, and International Affairs:		
Industrial Science and Technological Innovation	$12,899	
Intergovernmental and Public-Service Science and Technology	500	
International Cooperative Scientific Activities	11,583	
Policy Research and Analysis	4,600	
Science Resources Studies	3,138	
Coordinated Agency-Wide Research Activities	7,604	
Subtotal, Scientific, Technological, and International Affairs		$40,324
Program Development and Management		$63,182
Subtotal, obligations		$974,590
Unobligated balance carried forward		$2,347
Unobligated balance lapsing		$460
Total, fiscal year 1982 availability for Research and Related Activities		$977,397

Science and Engineering Education Activities Appropriation

Fund Availability

Fiscal year 1982 availability (appropriation)		$20,900

Obligations

Scientific Personnel Improvement	$16,745	
Science Education Development and Research	2,672	
Science Education Communication	1,186	
NSB Commission on Precollege Education in Mathematics, Science, and Technology	294	
Subtotal, obligations		$20,897
Unobligated balance lapsing		$3
Total, fiscal year 1982 availability for Science and Engineering Education Activities		$20,900

Special Foreign Currency Appropriation

Fund Availability

Fiscal year 1982 appropriation	$3,080	
Unobligated balance brought forward	1,550	
Recovery of prior year obligations	-2	
Fiscal year 1982 availability		$4,628

Obligations

Research and Related Activities		$3,655
Unobligated balance carried forward		$918
Unobligated balance lapsing		$55
Total, fiscal year 1982 availability for Special Foreign Currency Program		$4,628

Trust Fund

Fund Availability

Unobligated balance brought forward	$4,307	
Receipts from nonfederal sources	10,227	
Recovery of prior year obligations	597	
Fiscal year 1982 availability		$15,131

Obligations

Ocean Drilling Programs	$13,264	
Gifts and Donations	14	
Subtotal, Obligations		$13,278
Unobligated balance carried forward		$1,853
Total, fiscal year 1982 availability for Trust Fund		$15,131

Appendix C

Patents and Inventions Resulting from Activities Supported by the National Science Foundation

During fiscal year 1982, the Foundation received 102 invention disclosures and made rights determinations on 93 of those inventions. These resulted in dedication to the public through publication in 7 cases, retention of principal patent rights by the grantee or inventor in 84 instances, and transfer to other government agencies in 2 cases. The Foundation received licenses under 36 patent applications filed by grantees and contractors who had been allowed to retain principal rights in their inventions.

The Foundation published a new patent regulation on August 30, 1982 (*Federal Register*, vol. 47, no. 168, pp. 38124-30, to be codified as part 650 of title 45, *Code of Federal Regulations*). This new regulation implements the Bayh-Dole Act (35 U.S.C. section 200 *et seq.*) and allows small-business firms and nonprofit organizations, including universities, normally to retain the principal patent rights to their NSF-supported inventions. The allocation of rights to inventions made by other categories of grantees and contractors normally will continue to be made by the Foundation after inventions are identified—i.e., on a "deferred determination" basis.

Because the Bayh-Dole Act eliminates the need for institutional patent agreements, NSF cancelled all IPAs in September 1982.

The following U.S. patents issued from research supported by the National Science Foundation during fiscal year 1982:

Number	Title	Institution
4,268,465	Method of Accelerating the Cooling of Polymeric Articles	Massachusetts Institute of Technology (MIT)
4,273,624	Thin Platinum Films on Tin Oxide Substrates	University of Florida
4,278,646	Oxidative Removal of Hydrogen Sulfide from Gaseous Streams	University of California
4,292,242	Production of Amines	SRI International
4,293,654	Cell-Culture Microcarriers	MIT
4,293,783	Storage/Logic Array	MIT
4,297,615	High-Current Density Cathode Structure	University of California
4,305,880	Process for Preparing 24-Fluoro-25-Hydroxycholecalciferol	Wisconsin Alumni Research Foundation
4,307,241	Ring Expansion and Chain-Extension Process and Reagents	Wisconsin Alumni Research Foundation
4,311,343	Apparatus for Breaking Rock or Concrete	Terraspace, Inc.
4,315,149	Mass Spectrometer	University of Nebraska
4,316,140	Charge-Flow Transistors	MIT
4,317,084	Oscillator That Includes a Charge-Flow Transistor	MIT
4,321,086	Preparation of Micron-Sized Metal Droplets	Wisconsin Alumni Research Foundation
4,321,313	Electrogenerative Reduction of Nitrogen Oxides	Wisconsin Alumni Research Foundation
4,321,467	Flow Discharge Ion Source	SRI International
4,326,898	Method for Forming Material Surfaces	MIT
4,329,200	Method and System for Selective Alkaline Defiberization and Delignification	University of Washington
4,329,208	Method and Apparatus for Converting Ethylene to Ethylene Oxide	MIT
4,330,621	Assay for Aminoglycosides	Wisconsin Alumni Research Foundation
4,330,761	High-Power Gas Laser	MIT

Appendix D

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